GENERAL GEOLOGY AND SULFIDE MINERALIZATION OF DRY CANYON AND VICINITY, GUNNISON PLATEAU, SANPETE CO., UTAH.

by

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A thesis submitted to the faculty of the University of Utah in partial fulfillment of the requirements for the degree of

Master of Science

Department of Geology

University of Utah

June, 1967

This Thesis for the

Master of Science Degree

by

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March, 1967

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ACKNOWLEDGMENTS

The writer is deeply indebted to Professor Francis W. Christiansen under whose inspiring and able guidance this work was completed. Thanks are also extended to Professors Armand J. Eardley and Mead LeRoy Jensen for their helpful criticism of the manuscript.

Grateful acknowledgment is made to the United States Agency for International Development for the financial support without which this work would not have been completed.

The assistance in the field work rendered by A. Khadi is greatly appreciated.

The writer is grateful to Miss Sally Hutchings who typed the manuscript.

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An abstract of a thesis submitted to the faculty,
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ABSTRACT

The area of investigation, which lies on the eastern front of the Gunnison Plateau between Coal Canyon and Maple Canyon (south), is formed of formations of Upper Mesozoic and Cenozoic ages.

The formations of Upper Mesozoic age are represented by Twist Gulch-Upper Jurassic, Indianola undifferentiated-Upper Cretaceous, Price River-Upper Cretaceous, and the lower part of North Horn-Upper Cretaceous. The formations of Cenozoic Age are represented by the upper part of North Horn-Paleocene, Flagstaff-Paleocene, Colton-Eocene, and Green River-Eocene.

Of all the formations, the Twist Gulch is the only marine formation present in the area. The other formations represent deposition under fluviatile, fluvio-lacustrine, and lacustrine environments. The clastic sedimentary rocks account for more than two third of the total thickness of the strata exposed in the area. The North Horn formation constitutes as much as 2000 feet of clastic sedimentary rocks.

Igneous activity is indicated by the glass associated with the Flagstaff formation (limestone) and felsitic lava flows associated with the Green River formation. Some intrusions of quartz-monzonite porphyry occur west and north of the area of investigation.

The area is traversed by EW and nearly NS striking high angle normal dip-slip faults. A few high angle reverse faults are also present. In the eastern part of the area of investigation, recent

faulting has occurred. This faulting is mainly confined to recent alluvium and has given rise to prominent scarplets which strike NE-SW.

North of Dry Canyon, the North Horn strata are mineralized. The mineralization of the strata is mainly limited to sedimentary units in the basal part of the North Horn formation where galena, pyrite, and chalcopyrite occur.

A detail field work and laboratory studies revealed that galena, pyrite, and chalcopyrite associated with the North Horn strata are of epigenetic origin, and represent deposition at relatively low temperatures.

The regional relationship of the area of investigation supports an epigenetic origin for these sulfide deposits associated with the North Horn strata.

Evidence for the above conclusion consists of:

1. The localized occurrence of the sulfide deposits.
2. The occurrence of the quartz-monzonite porphyry intrusive bodies in adjacent localities.
3. Igneous activity during Green River time.
4. The typical replacement features present in the pyritized limestone and galena bearing sandstone and conglomerate.

INTRODUCTION

LOCATION OF AREA INVESTIGATED

The area investigated includes approximately 36 square miles located on the eastern slope of the Gunnison Plateau directly west of Ephraim, Utah (fig. 2).

The Gunnison Plateau lies south of the southern end of the Wasatch Mountains in the northwestern part of the Colorado Plateau Province (fig. 1). The Plateau rises to a maximum relief of 4500 feet. It extends in a north-south direction for 40 miles from Nephi at the northwest to Gunnison on the south decreasing in relief very gradually in the southern direction. A maximum width of 12 miles exists between the mouth of Little Salt Creek on the western front, and the mouth of Peach Canyon on the eastern front (fig. 2).

The general north-south trend of the plateau front is not continuous. The position of the front between Gunnison Reservoir and Axehandle Canyon (fig. 2), strikes almost north-south, but from a point north of Axehandle Canyon, the front veers strongly eastward "forming a striking promontory. This promontory is referred to as the 'Point of the Mountain'" (Speiker, 1948, p. 29).

The Sanpete Valley which lies to the east of the plateau and between the Wasatch Monocline and Gunnison Plateau is a north-south to northeast-southwest structural depression. It is of considerable structural and stratigraphic interest because of its location near

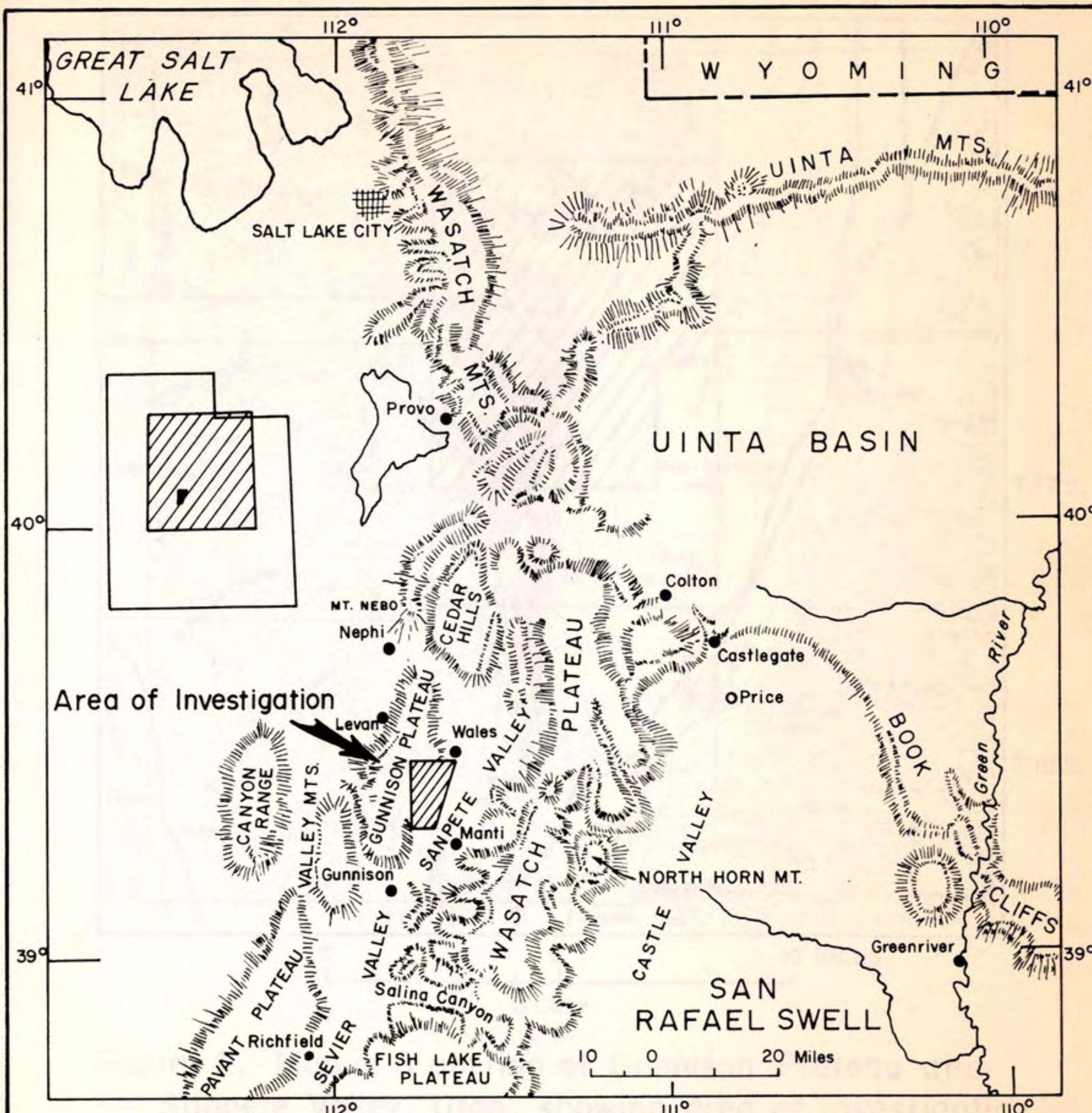

Figure I. Index Map of Part of Utah Showing Location of Gunnison Plateau and Area of Investigation, after Speiker, 1946.

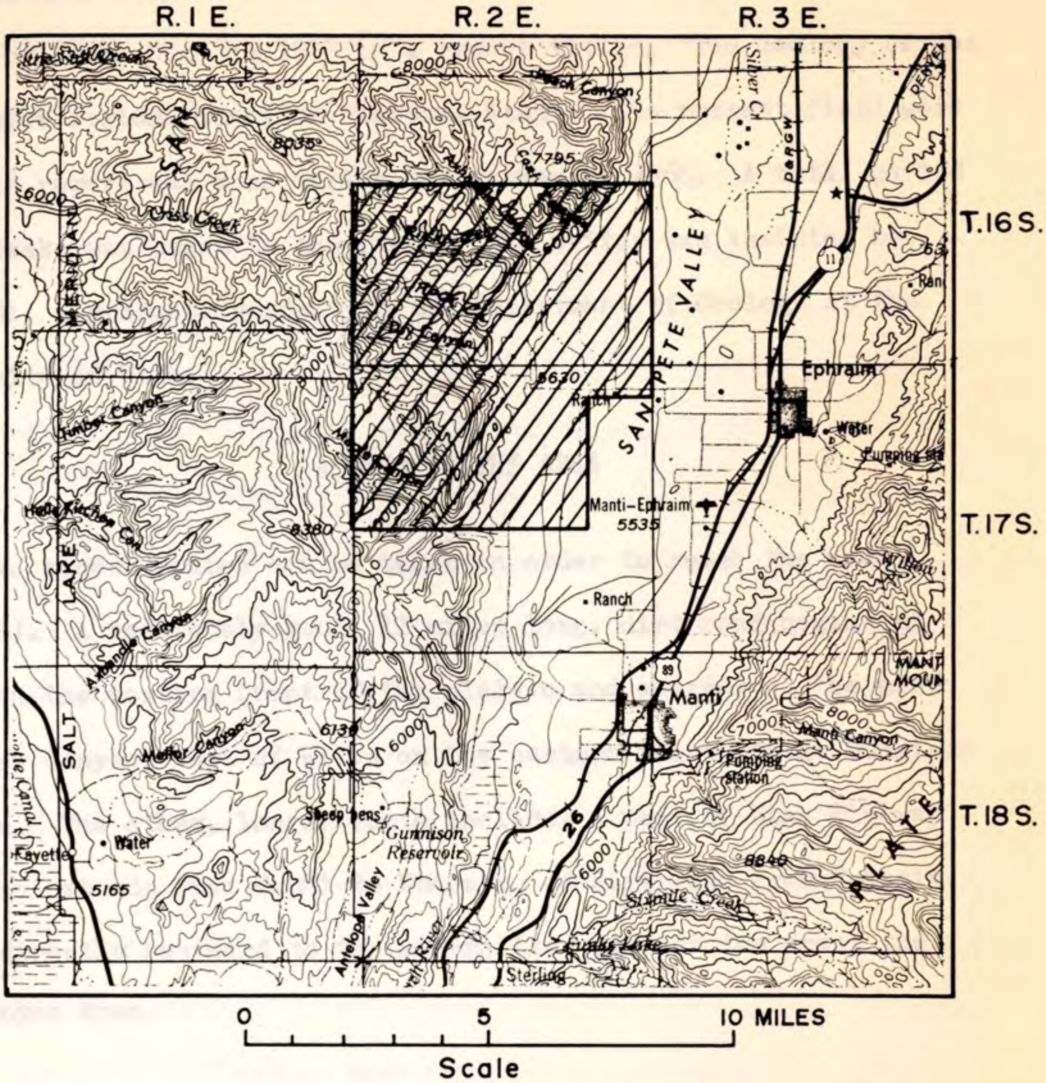

Figure 2. Map of a portion of Gunnison Plateau and Sanpete Valley, Utah, showing area of investigation, drainage, communications, and larger communities.

"the physiographic boundary between the Basin and Range region and the Colorado Plateaus..." (Hunt, 1948, p. 1).

The area studied in the report was originally mapped and described by R. E. Hunt in 1948 in a report titled, "The Geology of the Dry Canyon region, Gunnison Plateau, Utah". The present field work for this report was done during the summer of 1966. A total period of 12 weeks was spent in the field. The writer was assisted by A. Khadi, a graduate student in the Department of Geology at the University of Utah.

ACCESS TO THE AREA

Two access routes can be taken in order to reach the area (fig. 2). A moderately good, 12 miles long, dirt road begins at Levan on the western front of the plateau and emerges at the mouth of Wales Canyon, west of Wales on the eastern front of the Gunnison Plateau. The other, longer route includes a part of Utah Highway 16 which extends from Nephi to Ephraim. A dirt road from Ephraim leads directly westward to the mineralized part of the area, the Dry Canyon Area.

TOPOGRAPHY

Mount Baldy which lies to the north-west of the area is the highest point in the immediate area. It rises to an altitude of 8900 feet above sea level, and its relief is approximately 3400 feet above the Sanpete Valley floor. (The elevation of Sanpete Valley floor at Ephraim is approximately 5500 feet.)

The alluviated Sanpete Valley floor rises gradually to the base of the plateau which at the mouth of Dry Canyon is about 5800 feet elevated. Above this point, the plateau front rises rather abruptly to an elevation of about 7200 feet. At this point a marked change in slope occurs. From this point, toward the west, a gentle and undulating surface slopes upward to Mount Baldy (Hunt, 1948, p. 2).

DRAINAGE SYSTEM

The region where the writer carried out his investigation, and which forms the basis of this study, lies entirely to the east of the main drainage divide of the Gunnison Plateau (figs. 1 and 2).

The majority of the drainage systems of the area are ephemeral. During the spring run off and a period of torrential storms during July and August, when these streams receive sufficient quantities of water to cause flowage, they join the San Pitch River, the main perenial trunk stream flowing generally southward through Sanpete Valley and draining into Gunnison Reservoir west out of the town of Manti, Utah (fig. 2).

Five major drainage systems have developed in the area (fig. 2). All of the main tributaries have cut deep canyons into the eastern front of the plateau, and their innumerable tributaries have reduced the upper reaches of the plateau to middle to late youthful stage. Starting from the north and going south, the following five canyons form the major drainage system of the area (fig. 2). 1. Coal Canyon, 2. Axehandle Canyon (Northeast), 3. Rock Creek, 4. Dry Canyon, and 5. Maple Canyon.

In addition to the above mentioned five major drainage systems, many other small streams drain the eastern front of the plateau.

Hunt has described Axehandle Canyon in the following words:

"Axehandle Canyon is the one regularly flowing drainage system in the area. The yield of water from this Canyon even if constant, is exceedingly small. Nevertheless, it is immediately diverted upon reaching the Valley by the farmers and proves sufficient to irrigate a few acres of ...land... near its mouth" (Hunt, 1948, p. 5).

The writer while working in the area observed that all the larger farms and ranches are located near the mouth of canyons. However, the one located near the mouth of Axehandle Canyon is abandoned, no cultivation activity or grazing activity was observed during the entire period of field work.

Evidences of past flash floods in the area are furnished by the accumulation of huge boulders on the floor of the canyons. Some of the large boulders were transported farther east and scattered over the alluviated surface. Most of these boulders were removed and lands were used for agricultural purposes. However, the large boulders were left undisturbed. These boulders are seen sticking out of cultivated fields. Their actual size cannot be apprehended as they have been partly buried by repeated flash floods depositing a thick layer of alluvium.

A thick cover of alluvium extends all along the eastern front of the Gunnison Plateau. These alluvial deposits have developed into a thick layer because of the coalescing of several alluvium fans along the base of the plateau. The alluvial deposit in the area has been classified as either older alluvium or younger alluvium (geologic map of Utah). The younger alluvium occurs in the areas near the plateau and at the mouths of the canyons. Farther east in the lower parts of the valley the alluvium is older and there underlies a portion of the fertile soil of the Sanpete Valley.

CLIMATE

The central Utah falls in the semi-arid zone, and is characterized by sparse vegetation. The sparse vegetation is mainly due to limited rainfall. The annual amount of precipitation varies between 10-20 inches. However, this is not fairly uniformly distributed throughout the year. The precipitation is more during winter than summer.

The maximum temperature during the day in the month of July reaches 90° F, where as the minimum temperature ranges between 65-70° F. Last summer was exceptionally hot and dry. With the exception of a few days, the day temperature rose to above 90°F.

The winter temperatures are said to range from 14° F. to 50± F. during the month of January. The writer did not record exact temperatures characteristic of winter season. However, the data which are available from previous reports substantiate the above mentioned temperatures.

VEGETATION

As mentioned above, the vegetation is very sparse. The mountain slopes are nearly bare of any notable vegetation. The whole area is characterized by a secondary growth which is the result of reseeding. The original vegetation cover was depleted by the pioneers, as a result of which a primary or original community of vegetation is lacking. The absence of primary succession of vegetation can be attributed to heavy lumbering, a practice of the pioneer settlement era, which dominated the entire United States of America's forest regions.

The sparse vegetation of the area differs considerably within a given stand. The vegetation at higher levels is considerably different from that on the lower levels.

Mesquite, tall prairie grass, greaswood, sage, and creosote dominate the low lands. However, there are regions which lack any sort of vegetation. These regions represent over-grazed lands. Their condition is poor and are favorable spots for the erosion of soil by run-off.

The highlands are considerably greener than low lands. Cattle trails are practically absent. Maple, oak, conifers, and fir trees dominate the highlands. These in no way represent a primary or original succession. The entire vegetation cover on the highlands is the result of reseeding.

The areas east of Wells managed by the U. S. Forest Service, forms a portion of the National Forest. Grazing and lumbering is about non-existent in this region. Proper care is taken to stabilize the steep water shed on the west side of Sanpete Valley. This is done in order to reduce the danger of floods and soil erosion, which is extremely important for the economy of the communities located on the eastern side of this area.

CULTURE

The eastern front of the Gunnison Plateau marks the western limits of the Sanpete Valley. No large communities are located in the area where the writer worked. Ephraim is located farther to the east. This community, as are the other communities, is mainly supported by agriculture and transit trade. Turkey and chicken farming are the two major industries of the area. Manti, another larger community is located south of Ephraim. This town is also an agricultural community.

Very few irrigation systems are present in the area. San Pitch River and its tributaries are the chief source of agricultural waters (fig. 2).

The tube wells, canal irrigation, and rain have converted Sanpete Valley, once a semi-arid and sage covered valley, into a beautiful and luxurious green patch. Gilliland reports that Sanpete Valley is responsible for the production of many agricultural products in Utah (Gilliland, 1948, p. 8).

U. S. Highway 89 which connects Salt Lake City through Sanpete and Sevier Valleys, is the main highway parallel to the eastern front of the plateau passing through Ephraim and Manti (fig. 2) and connects with U. S. Highway 28 at Gunnison, a town situated at the southern extremity of the Gunnison Plateau. Utah State Highways 30 and 116 also pass through the eastern front of the Gunnison Plateau. State Highway 30 connects Wales, Ephraim and Manti.

MAPPING METHODS

There are no topographic maps on a scale that could be used for mapping this part of the Gunnison Plateau. The maps that are available are old and not usable.

The writer attempted to use a topographic map published by U. S. Geological Survey in 1965. The original map scale was 1:250,000, with a contour interval of 200 feet. This map was used for locating various canyons and major relief features.

Thus because of the above mentioned limitations, aerial photographs released by the U. S. Soil Conservation were used as a base for mapping. Because of the non-availability of a controlled mosaic, the original photos, used for mapping as a base were used to prepare an overlay. However, no attempts were made to remove distortion.

The following aerial photographs were obtained from the United States Department of Agriculture, Agricultural Stabilization and Conservation Service, Western Laboratory, Aerial Photography Division 2505 Parley's Way, Salt Lake City, Utah

CVW 5V-96 through CVW 5V-101

CVW 7V-83 through CVW 7V-89

CVW 10V-76 through CVW 10V-78

STATEMENT OF PROBLEM

The writer was assigned to prepare a geologic map of the area and determine the nature and origin of the galena and pyrite (specifically to determine if the pyrite and galena is syngenetic or epigenetic) mineralization in the sandstone beds of the North Horn formation exposed north of Dry Canyon.

GENERAL FEATURES OF MINERALIZATION

It was found that the metaliferous strata occur in the North Horn formation, in the area between the eastern protrusion of the Gunnison Plateau front and the Dry Canyon proper (plate 1).

In this area the North Horn formation shows all the textural variation in grain size. In the lower part it is mainly conglomeratic and in upper part it is composed of alternating strata of limestone, sandstone, and conglomerate.

Metallic minerals occur in the lower part of the North Horn formation.

Galena is the dominant metallic mineral in the lower part of the North Horn formation exposed north of Dry Canyon. However, the upper part of the formation shows considerable amounts of pyrite (chalcopyrite?). Oxidation of pyrite and chalcopyrite (?) and the development of oxides and hydroxides in the sandstone has colored the strata red to rusty brown.

From the number of abondoned mines and pits, it is apparent that local prospectors have been aware of the metallic occurrences in this region for a long time. At present, a local miner and prospector from Ephraim is prospecting in the area and is mining the mineralized sandstone in an open pit operation.

It is noteworthy that none of the investigators either from Ohio State University or any other organization reported the occurrence of galena and pyrite in sandstone beds of the North Horn formation. Hunt (1948), who is the only person who carried out geological investigations specifically in Dry Canyon area reported no occurrences of metallic minerals.

From the exposures around the Dry Canyon region, it is very much apparent that there is no large scale hydrothermal alteration of the wall-rock, fissuring, or vein formation. The only indications of metallic occurrences are inferred from the coloration of the rock due to weathering of the sulphides or from very close examination of rock strata. A few vertical joints traverse the North Horn formation in this area. These joints are lined by the crystals of calcite, a variety known as 'dog tooth spar'. The occurrence of metallic minerals is not persistent and the mineralized zones pinch out in either direction from the apparent source of mineral. Large crystals of pyrite occur in the sandstone but are widely scattered.

PREVIOUS WORK

The latest record of detailed geological work in this part of the Gunnison Plateau, which is available, is an unpublished masters thesis by R. E. Hunt of Ohio State University. This thesis was written in 1948 and is the last geologic work dealing with the stratigraphy, lithology and structural geology of the area.

Prior to Hunt's work a number of reconnaissance type surveys were carried out, not specifically in the area of discussion but on the Gunnison Plateau as a whole and around it.

Most of the early work is confined to northern part of the plateau, which is mainly due to the economic considerations related to the occurrence of coal in the North Horn formation. Consequently much work and attention was devoted to this part of the plateau.

Richardson (1906), published a number of articles about the Coal Fields in the vicinity of Wales.

The first geological recconnaissance map was published sometime after 1875, when the region was surveyed in two missions in 1872 and 1875 respectively. The region was surveyed by G. M. Wheeler for the United States Geological and Geographical Survey. A geological map was compiled after this recconnaissance survey was completed. Another map accompanied professional paper 111 by B. S. Butler, G. F. Loughlin, V. C. Heiks, and others, (1920). This paper assigned a Tertiary age to the rocks of the area now under discussion.

"In the year 1895, the Manti Sheet, a recconnaissance topographic map was published by the Powell Survey. It was on a scale 1/250,000 with a contour interval of 250 feet. Consequently it lacked the details necessary for a comprehensive study of the area" (Hunt, 1948, p. 9).

Many other non-geological maps have been published by U. S. Soil Conservation Department since then. However, they are no better for geologic mapping than those prepared by their predecessors. The scale of these maps is too small to be used for geological mapping and consequently they are unfit for any consideration as far as geologic mapping is concerned.

In 1939, the United States Soil Conservation Commission flew an aerial survey over the area. Consequently aerial photographs and planimetric maps are now available.

A number of other workers have contributed to the knowledge of the regional geology.

Cope (1880) and Dutton (1880), both published papers on the Geology of central part of Utah. Cope (1880), described the Manti beds, which later were reassigned to the Green River Formation by Speiker in a paper titled "Cretaceous and Tertiary Formation of the Wasatch Plateau, Utah" (Speiker, 1935, p. 451). Dutton (1880) described the geology of high Plateaus of Utah.

Extensive investigations have been accomplished by Speiker and his associates on the areas lying east of the area under discussion. Speiker (1928), and Baker (1928) also carried out investigations in Salina Canyon District. They published a joint report titled "Geology and Coal resources of the Salina Canyon District, Utah".

Schoff (1937) discussed the geology of Cedar Hills. He published his findings in a doctoral thesis at Ohio State University. The Cedar Hills is a group of low lying hills in the northern part of Sanpete Valley.

Eardley, Gilbert, and Loughlin have contributed a great deal of information about the Southern Wasatch Mountain, which lies farther north. A bibliography which appears at the end of this report gives the titles of various works and the year of the publication of their work.

Besides the above workers, various investigators mainly from Ohio State University have described the geology of the Gunnison Plateau in a number of dissertations either for masters degrees or doctoral degrees. These dissertations pertain to the stratigraphy, lithology, or structural geology of the Gunnison plateau or areas around it.

The following authors from Ohio State University have contributed to the geological information concerning the Gunnison Plateau.

Taylor (1948), discussed the geology of the Gunnison Plateau front in the vicinity of Wales, Utah. Whereas Gilliland (1949) described the geology of the Gunnison Quadrangle in a doctoral dissertation at Ohio State University. This work was published by the University of Nebraska at Lincoln in 1951, under the publication program titled as 'University of Nebraska, News Series'. Hardy (1949) described the 'Stratigraphy and Structure of the Arapian Shales and the Twist Gulch Formation in Sevier Valley', in a doctoral thesis. Katherman (1948), and Gills(1950) described the Lithology of the Flagstaff

Limestone on the Eastern front of the Gunnison Plateau and around Spring City-Manti Areas respectively. Lee (1950), Bonar (1948), and Wilson (1949) described Petrography of the Price River Formation, Geology of Ephraim area, and Geology of the upper Six Mile Canyon Area respectively. Hardy (1948) discussed the stratigraphy and structure of a portion of the western margin of the Gunnison Plateau in a master's degree thesis. He described formations ranging in age from upper Cretaceous to Recent. The area of Hardy's investigations though, lies on the western front of the Gunnison Plateau, where the Twist Gulch formation is extensively exposed but characteristically shows the absence of any trace of the Twist Gulch formation. Hunt (1950), Zeller (1949) and Babisak (1949) discussed the stratigraphy and structure of portions of the Gunnison Plateau's northern, west central, and south eastern fronts respectively. Their work contains very little new information except each work is a pioneer work. There is practically no descrepancy in their correlation and description of various formations.

Besides the above mentioned investigations the following authors have also contributed to the geological information of the Gunnison Plateau: Washbur (1948), Bayley (1950), Frazier (1951), Fagadau (1949) and Johnson (1949).

It is noteworthy that in the first half of this century all the major investigations were carried out by graduate students of Ohio State University under the guidance of Dr. E. M. Speiker. Speiker has conducted an almost continuous series of summer camps in this area foı the students of Ohio State University. From the voluminous work done by Speiker and his students it is apparent that Speiker is a foremost authority on the geology of Central Utah. However, one wonders how all the workers from Ohio State University, who rendered a series of master and doctoral dissertations failed to take note of the occurrence of metaliferous strata in the North Horn formation exposed north of Dry Canyon.

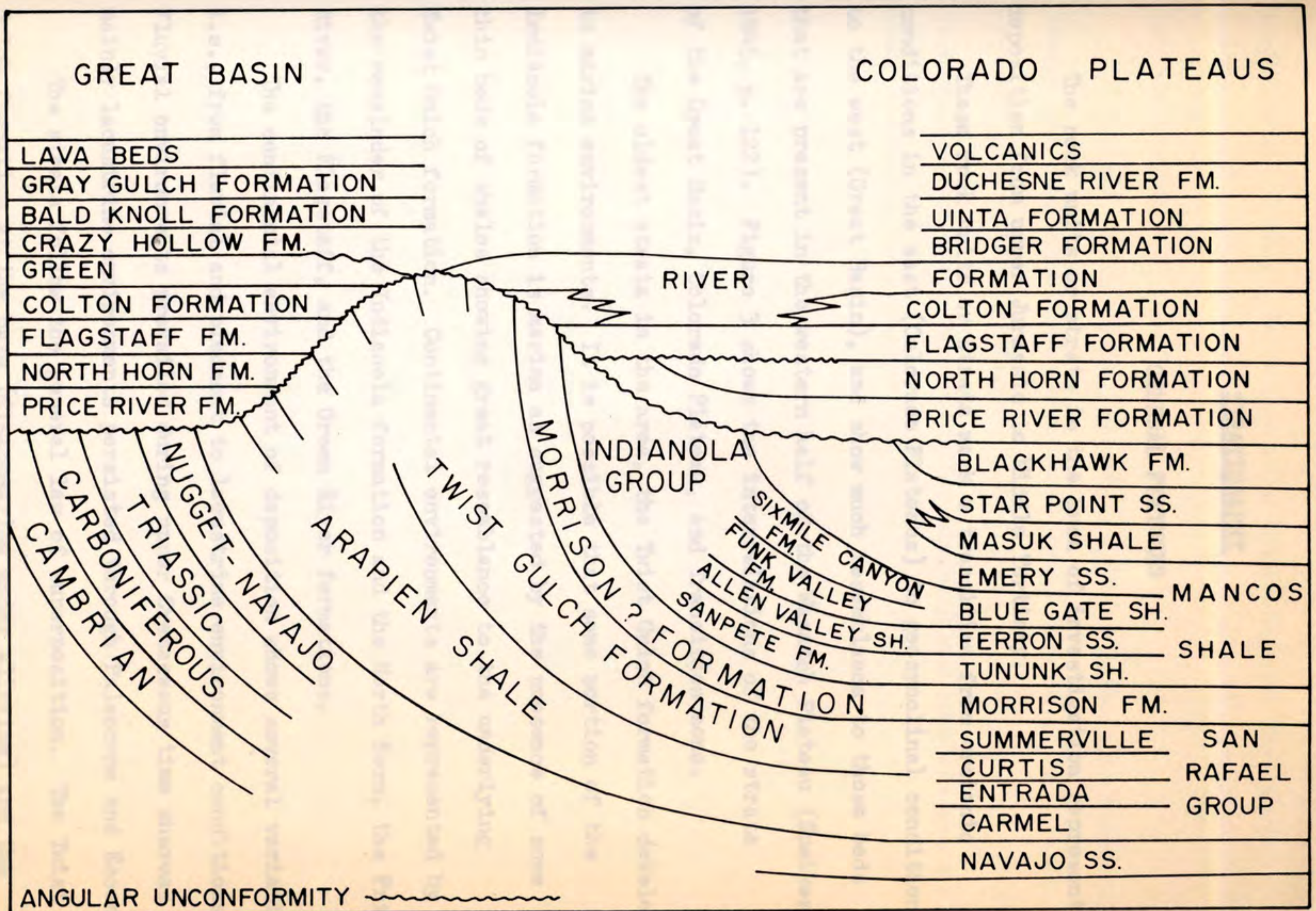

Figure 3. Interrelations of the Strata of Great Basin, Colorado Plateau, and Transition Zone. Modified after Speiker, 1949, page 11.

STRATIGRAPHY

GENERAL FEATURES

The rock units or strata in the area of investigation represent deposition from upper Jurassic to Middle Tertiary.

These rock units or strata mark a transition from cratonic conditions in the east (Colorado Plateaus) to geosynclinal conditions to the west (Great Basin), and show much resemblance to those beds that are present in the western half of the Wasatch Plateau (Speiker, 1946, p. 122). Figure 3 shows the interrelations of the strata of the Great Basin, Colorado Plateau, and Transition zone.

The oldest strata in the area, the Twist Gulch formation developed in marine environments. It is possible that some portion of the Indianola formation is marine as suggested by the presence of some thin beds of shales showing great resemblance to the underlying Twist Gulch formation. Continental environments are represented by the remainder of the Indianola formation and the North Horn, the Price River, the Flagstaff, and the Green River formations.

The continental environment of deposition shows several variations, i.e., from fluvial and piedmont to lacustrine environment conditions. Fluvial environments prevailed during upper Cretaceous time whereas mainly lacustrine environments persisted through Paleocene and Eocene.

The strata follow the general law of superposition. The Twist Gulch formation at the base (disappearing under alluvium) and the Green River at the top (occurs mainly at the crest of highland). The rest of the strata or the intervening strata between the oldest and topmost occur normally except where subjected to faulting and intense folding.

A summary of the various formations, their lithologic characteristics and thicknesses are given in Table 1. The table is exactly the same as presented by Speiker (1946) later adopted by Hunt (1948). However, the thickness figures differ slightly and some changes in nomenclature are suggested.

Age		Formation	Lithologic Characteristics	Thickness (feet)
CENOZOIC	Eocene	GREEN RIVER	*Limestone, white to gray; shale, gray to gray-green; sandstone, gray to cream.*	520'
		COLTON	*Shale, variegated, mostly red and gray; limestone, light-gray to white; sandstone, brown, green and pink.*	837'
	Paleocene	FLAGSTAFF	*Limestone, dense, fine to lithographic, gray, grayish-white, and black, fossiliferous, algal balls abundant.*	350' - 450' ±
-?-	-?-	NORTH HORN	*Conglomerate in basal part, rounded to sub-rounded dark limestone pebbles and light colored quartzite pebbles present, cross-bedded sandstone, gray, brown, and tan, metalliferous locally; **	1699' - 3000' ±
MESOZOIC	Upper Cretaceous	PRICE RIVER	*Conglomerate, rounded to sub-rounded pebbles varying in size from 3 inches to 10 inches, mostly quartzitic, tan to brown, massive cliff forming.*	0 - 550'
			UNCONFORMITY	
		INDIANOLA (UNDIFFERENT-IATED)	*Conglomerate, variegated, ranging in color from white to light-gray; sandstone, gray, coarse to medium; shales, orange-red.*	0 - 405'
			UNCONFORMITY	
	Upper Jurassic	TWIST GULCH	*Shale, red and gray, gypsiferous at places, blocky; siltstone, red; sandstone, reddish-gray.*	960 +

Table I. Stratigraphy of Dry Canyon and Vicinity, Gunnison Plateau, Sanpete Co., Utah.

**Limestone, tan and gray, algal balls occurring mostly in limestone.*

JURASSIC SYSTEM

UPPER JURASSIC

TWIST GULCH FORMATION

Definition, Type Locality, and Regional Nomenclature.

The name Twist Gulch was assigned by Speiker (1946, p. 123-124) to the upper member of the Arapien Shale formation of Upper Jurassic age. Previously the whole body of these sediments (Speiker's Arapian Shale) was not differentiated and was collectively referred to as Jurassic Shale.

Since Speiker coined this term, subsequent investigators have revised the rank of the Twist Gulch, and have raised it to formational rank. In fact, both Speiker and Hardy (1949) revised the scheme of nomenclature. Thus Arapian Shale, which was originally divided into two members, the Twelve mile Canyon member (Lower member) and the Twist Gulch member (Upper member), now applies to the Twelve mile Canyon member which has been also raised to formational rank.

The body of the sediments referred to as the Twist Gulch formation is of marine origin and consists of red and gray shale, sandstone, and siltstone. The shale is gypsiferous and at several places gypsum and rock salt occur in well defined strata.

The type locality, after which the former member and now the Twist Gulch formation was named, lies in the north side of Salina Canyon, in Salina Canyon district (Speiker, 1949, p. 123).

"The nomenclature of ...rocks...referred" to as Twist Gulch formation and the Arapian Shale formation "presents a problem in that the area lies between two regions in which Jurassic strata, probably equivalent in large part to the central Utah beds, have been classified in two different schemes both of which have been widely used. Instead of being clearly correlatable with either of these two sections, the strata of central Utah are in important respects different from both" (Speiker, 1946, p. 123).

The nomenclature evolved by Veatch (1907, p. 56-58) for the Jurassic section in Southwestern Wyoming is applied and extensively used for the marine Jurassic formation exposed in the north, i.e., Wasatch and Uinta Mountains, and the adjacent areas in northwestern Utah and southwestern Wyoming. See Table 2 (in pocket). Whereas the nomenclature established for the section of the San Rafael Swell by Baker, Dane, and Reeside (1936, p. 3) has served for east and south in the Colorado Plateaus as a standard. See Table 2 (in pocket).

Thus because of the absence of any dependable evidence for correlation of the Twist Gulch and the Arapien Shale formations with either northern sections or southern sections, no pre-existing term has been used to designate 'Jurassic Shale' now referred to as Arapien Shale by Speiker (1946), and Twist Gulch formation by Hardy and Speiker (1949).

The Twist Gulch formation of central Utah is roughly correlatable to the upper portions of the San Rafael group. However, the Twist Gulch formation cannot be differentiated and split into various units with any accuracy comparable to the accuracy involved in the sub-division of the San Rafael group. It is roughly correlatable with the Curtis and Summerville formation of the San Rafael group.

Distribution

The Twist Gulch formation, which was originally defined by Speiker (1946, p. 123-126) as the Upper member of the Arapien Shale and later redesignated as a formation by Hardy and Speiker (1949) crops out in the north side of Salina Canyon, the type locality. It crops out conspicuously in a belt 2 to 3 miles wide, on the east side of Sevier Valley along the margin of the Wasatch Plateau. "It begins at the southern end of Sanpete Valley, near the main highway about 5 miles east of Gunnison, and extends southward past Salina to a point about 6 miles southeast of Richfield" (Speiker, 1946, p. 124). In these localities the upper limits of Twist Gulch formation is found clearly exposed in Salina Canyon. The overlying beds in this region probably belong to Morrison (?) formation. These beds comprise of Sandstone, Conglomerate, and Variegated shale (Speiker, 1946, p. 124). The base of the Twist Gulch formation was recently defined by Hardy (1949).

Gilliland (1951, p. 10-15), who described the geology of the Gunnison Quadrangle did not differentiate the Twist Gulch formation from the Arapien Shale, but mapped the entire formation as a undifferentiated single unit. However, there are indications that the bulk of the Gillilands' undifferentiated unit is the Twist Gulch formation.

Speiker (1949) and Hardy (1949) who described the stratigraphy and structure of the Arapien shale and the Twist Gulch formations of

Sevier Valley have differentiated the Twist Gulch formation from the Arapien Shale formation.

In addition to the occurrences of the Twist Gulch formation in a belt along the margin of the Wasatch Plateau, it also occurs in scattered outcrops through Sevier Valley, and in a thick and continuous belt extending all along the western base of the Gunnison Plateau. It outcrops at the southern end of the Wasatch Mountains and is extensively exposed in the southern foothills of Mount Nebo. These scattered occurrences have been described by Eardley (1933, p. 331).

The Twist Gulch formation is also exposed in discontinuous outcrops along the eastern base of the Gunnison Plateau.

Speiker (1946), recognized outcrops of the Twist Gulch formation near Thistle and in the district north of Indianola.

Gilliland (1951, p. 13), reports the occurrence of the Twist Gulch formations outcrops "along much of the western edges of the Jurassic badlands; at the south end of Green River Hogback located immediately south of Willow Creek, and in Redmond Hills" (Gilliland, 1951, p. 13).

The Twist Gulch (?) formation exposed in Willow Creek area and Redmond Hills is salt bearing. The rock Salt is the dominant saline constituent of the strata in the Redmond Hills localities (Gilliland, 1951, p. 13).

Lithology and Thickness

The Twist Gulch formation (former upper member of Arapien Shale later redesignated by Hardy (1949) and Speiker (1949) as formation), consists of thin bedded dark red massive to chocolate siltstones, sandstones and shale. It is infact, a variegated series showing a great variety of color and textural variations.

In localities other than eastern and western fronts of the Gunnison Plateau, it consists of compact red salt bearing shales, thin bedded red siltstone, and shale. Interbedded with these lithologies are many thin beds of greenish, gray, grayish-white siltstones. Occasionally lenticular layers of coarse grained sandstone occur at various levels.

On the eastern front of the Gunnison Plateau the Twist Gulch formation occurs at the base of front and passes under the alluvium of the Sanpete Valley. The occurrence of the Twist Gulch formation is fairly persistent through the entire eastern front starting west of Wales. However, it thins and thickens both in the northeast and south of the area of investigation. The Twist Gulch formation occurs in a thin belt varying in thickness from a few feet to several hundred feet.

As stated previously the Twist Gulch (?) formation consists of Salt-beds in Redmond Hills and Willow Creek, however, it lacks any mentionable quantity of saline deposits on the eastern front of the Gunnison Plateau. Except for the presence of few very thin laminae of gypsum along the bedding planes and some veins cutting across the strata, no other saline deposits are present.

Hardy (1949) recognized five units in the Arapien Shale. The discussion of all the five units will be out of place and beyond the scope of the discussion intended under Twist Gulch formation. However, Hardy's (1949) Unit No. 5 designated by him as 'Unit E' consists of

"Brick red silty shale, locally salt-bearing. The salt appears to be stratified and commonly "contains a considerable amount of red clay".

The upper parts of undifferentiated Arapien Shale in the Gunnison Quadrangle show great affinities with Hardy's 'Unit E' Which may be the equivalent of the Twist Gulch formation. But on the basis of the occurrence of silt deposits, Hardy's 'Unit E', can be regarded as the upper member of Arapien Shale. Although the Twist Gulch formation exposed along the eastern front of the Gunnison Plateau, shows resemblance to 'Unit E' of Hardy in broader aspects, however, is in sharp contrast as no salt deposits are associated with it.

In the Gunnison Plateau the thickness of the Twist Gulch formation cannot be determined firstly because there are several localities where the Twist Gulch cannot be differentiated from the Arapien Shale, secondly, the intesne folding and faulting prevents accurate measurement and establishment of a definite thickness. Hardy (1949) reported at least 1910 feet of the Twist Gulch formation exposed in Salina Canyon. There the beds are partially covered and disrupted by faults. Speiker (1946, p. 123), assuming a normal sequence (the fault runs parallel to bedding plans) estimated a total thickness 3000 feet in the same locality.

The exposed thickness of the Twist Gulch formation exposed along the eastern front of the Gunnison Plateau and in the area of investigation, varies from a few feet to several hundred feet. In the area of investigation, the maximum thickness of the formation is about 960± feet as measured by the writer.

Section of the Twist Gulch formation measured at the mouth of Dry Canyon and base of the northern wall.

Base Covered	Feet	Inches
Shale, gray, dense and compact	8	
Shale, red, blocky, gypsum partings	13	8
Sandstone, light gray to grayish white fine to medium grained	1	10
Shale, red, compact and hard, traversed by joints which divide the unit into blocks . . .	5	6
Sandstone, gray, friable, shaly partings of red color, fine to medium angular to sub-angular .	60	6
Sandstone and shales, alternating, red, medium grained, shales, sandy and traversed by gypsum veins	870	6
Total thickness	960	

Relation to Adjacent Formations

The Twist Gulch formation is the oldest formation in the area and its base is not exposed because it is covered by alluvium or valley fill which covers the floor of Sanpete Valley.

The Twist Gulch formation is overlain in the area between Dry Canyon and Maple Canyon either by the Price River formation or the North Horn formation. At no locality it is found to be overlain by the next immediate younger formation, which is the undifferentiated Indianola formation. However on the basis of exposure in other regions (north to Coal Canyon) where the Twist Gulch formation is overlain by the Indianola formation, it is observed that the overlying Indianola formation is separated from the Twist Gulch formations by an unconformity. The contact of the Twist Gulch formation with either the Price River formation or the North Horn formation is unconformable. The Twist Gulch formation is separated from either formation by an angular unconformity (Hunt, 1948, p. 19). Only near Wales (not in area) the Twist Gulch formation is overlain by the Morrison (?) formation.

The Morrison formation, which has been observed and described from various localities of central Utah is conspicuously missing from the area. The same is true for rocks of the Lower Cretaceous age which are altogehter absent. Speiker (1946, p. 158) has suggested that the absence of the Morrison and the Lower Cretaceous formation is not due to extensive erosion but rather due to the starvation or non deposition in the basin or its neutrality.

Age and Correlation

In a regional correlation scheme, Schoff (1937) correlated the Twist Gulch formation (the then upper member of the Arapien Shale) with the Twin Creek in the vicinity of Salt Lake City and of the San Rafael group of southern western Colorado.

A generalized correlation of the Twist Gulch formation with the San Rafael group of southeastern Utah was suggested by Speiker (1946, p. 123-125) in his original scheme of nomenclature for the rocks of central Utah. He suggested an Upper Jurassic age for the Twist Gulch formation. His correlation was strengthened by Hardy (1949) who confirmed that the Twist Gulch formation was correlatable with the Entrada, the Curtis, and the Summerville sequence of the San Rafael Group of east-central Utah. The fauna of the middle units of Twist Gulch show remarkable affinities to fauna found in Curtis formation. Thus on lithologic, stratigraphic, and paleontologic evidences, the Twist Gulch is correlatable with the upper formations of the San Rafael group. The Twist Gulch formation is also roughly correlatable with the Pruess of north central Utah, southwestern of Idaho, and southwest of Wyoming. See Table 2 (in pocket).

On the basis of above mentioned evidences a late upper Jurassic age for the Twist Gulch formation seems to be most suitable.

CRETACEOUS SYSTEM

UPPER CRETACEOUS

INDIANOLA GROUP UNDIFFERENTIATED

Definition and Type Locality

The term Indianola group was given by Speiker to a sequence of undifferentiated rocks exposed near Indianola and found in scattered as well as continuous outcrops in various localities of central Utah. These strata are a heterogeneous assemblage of conglomerate, sandstone, limestone and shale, of both marine and non-marine origin, and show a great variety of color and lithology (Speiker, 1946, p. 126).

At localities where this heterogeneous assemblage is divisible into distinct units the term Indianola Group (differentiated) is applied, and where a refined stratigraphic break down of various units is not possible the term Indianola Group (differentiated) is applied, and where a refined stratigraphic break down of various units is not possible the term Indianola Group Undifferentiated is applied (Speiker, 1946, p. 126).

Thus "Marine strata of Colorado age exposed at three localities on the western border of the Wasatch Plateau" namely "Salina Canyon, Six mile Canyon, and Lake Fork east of Thistle" are designated as 'Indianola group' because at the above mentioned localities the strata are easily subdivided. However, in areas where the occurrences are patchy and limited, such division is not possible. The Indianola district, the area between Salina and Gunnison, and the Gunnison

Plateau fall within such category. In these areas the units, which appear divisible in other localities, are impossible to differentiate and thus the nomenclature established for well identifiable and divisible units cannot be extended and used for un-identifiable and indivisible units. In view of the above mentioned difficulties, Speiker (1946, p. 127), suggested ..."that the entire unit be called the Indianola group, subdivided into formations where consistently possible, undifferentiated where not". Speiker (1946, p. 127) recognized 4 distinct units in the area southwest of Manti. Each Unit is named after the type locality.

Unit 4 Six mile Canyon formation

Coarse-grained gray sandstone, and conglomerates containing a coal-bearing member of finer grain.

Unit 3 Funk Valley formation

c. Sandstone, white, green and buff to brown 700 feet.

b. Gray marine shale 650 feet.

a. Sandstone and interbedded the shale. 900 feet.

Unit 2 Allen Valley Shale

Mostly gray marine shale, evenly bedded.

Unit 1 Sanpete formation

Sandstone, brown, ochre, buff and gray

Shale, mostly sandy.

Conglomerate, gray.

Distribution

A number of localities were mentioned under Speiker's (1946) discussion 'Definition and Nomenclature' where the Indianola group is found exposed. However, there are many other localities where outcrops belonging to the Indianola group are exposed. These outcrops are found exposed along the northern and southern sections of the Gunnison Plateau. The Unit is exposed on the western side of the Gunnison Plateau and extends from Nephi in north to Levan on the south. Schoff (1937), reported a thick section of the Indianola group undifferentiated from the Cedar Hills area.

In the area of investigation only one definite outcrop of the Indianola group undifferentiated is exposed. The unit crops out along the eastern margin of the Gunnison Plateau front. The northern and southern limits of this exposure are Axehandle Canyon and Rock Creek respectively, (see geologic map) North of Axehandle Canyon and at the base of the 'Point of the Mountain', a thick patch of the Indianola group (?) undifferentiated is also exposed.

Lithology and Thickness

The unit exposed in the area of investigation characteristically consists of gray to white conglomerate, sandstone and orange red shale. Thin beds of gray to white quartzite also occur at various levels within the main unit. All the above mentioned lithologies occur interbedded. When traced laterally over longer distances, these layers show a distinct lateral variation. See detailed stratigraphic section on page 34.

The conglomerates are mainly composed of black limestone pebbles, measuring about 2 inches in diameter. These pebbles are rounded to subrounded, and are imbedded in a calcareous sandy matrix.

The Indianola(?) Conglomerate north of Axehandle Canyon is composed of large pebbles. The size of the pebbles is about 8 inches and the color of shale layers is a sort of rusty brown than the usual orange red color which makes the Indianola group undifferentiated as the most conspicuous formation of the area. In the writers opinion this exposure seems to be a continuation of the Price River formation exposed farther north in Wales Canyon.

The Unit exposed in the area is mainly a continental deposit, deposited under fluviatile and flood plain environments.

The measured thickness is about 405 feet. See stratigraphic section. However, this thickness does not give a true picture of the total thickness of the unit as the unit passes under the alluvium or valley fill.

Section of the Indianola Group undifferentiated measured at the base of the eastern extension of the Gunnison Plateau in to Sanpete Valley, between Rock Creek and Axehandle Canyon.

Base Covered	Feet	Inches
Shale, red, granular and sandy	60	
Sandstone, white, medium grained, angular to sub-angular, loosely cemented to friable . .	20	
Conglomerate, red, mostly black limestone pebbles, varying in size from $\frac{1}{4}$ inch to $6\frac{1}{2}$ inches . . .	10	

Base Covered	Feet	Inches
Sandstone, white to grayish-white, medium to coarse, angular to sub-angular, quartzose . .	22	
Conglomerate, red, quartzitic pebbles mostly pink and light color dominant, pebbles sub-rounded to rounded, sandstone leures at various levels, coarse grained	52	
Sandstone, gray, very fine grained surface mottled	2	6
Shale, orange red, hard and dense	52	
Sandstone, red, fine grained, medium grained, equigranular, mostly angular, compact and well cemented	1	6
Shale, orange red	74	6
Conglomerate, red, mostly composed of black limestone and light-colored quartzite pebbles, pebbles vary in diameter from $\frac{1}{2}$ to 2 inches. Pinches out laterally, massive and lenticular	110	
Total thickness	405	

Relation to Adjacent Formations

In the area of investigation the Indianola group undifferentiated unconformably overlies the Twist Gulch formation.

In areas other than Eastern front of the Gunnison Plateau, the Indianola group undifferentiated is succeeded by the next younger

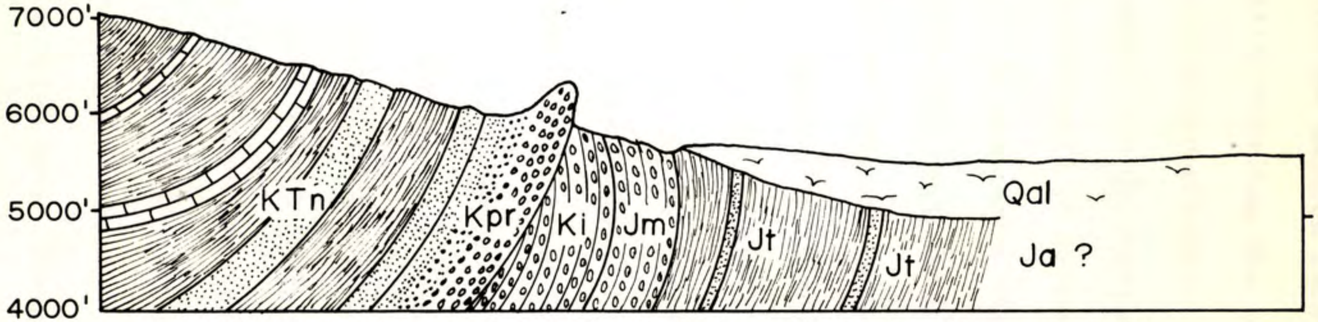

Figure 4. Gunnison Front at Wales, North to Axehandle Canyon (Figure after Speiker, 1949)

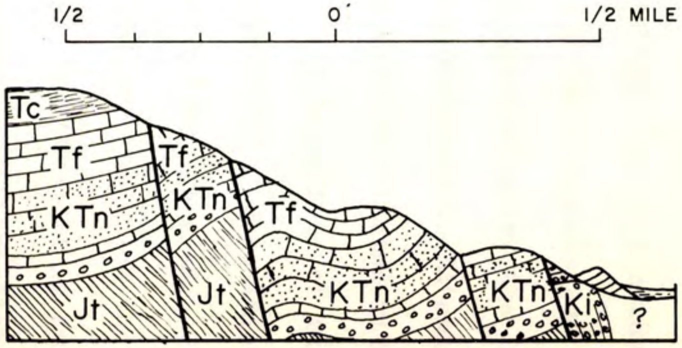

Figure 5. Section Across Eastern Front of the Gunnison Plateau South to Axehandle Canyon.

0 — 1 MILE

Qal	Alluvium
Tc	Colton Formation
Tf	Flagstaff Formation (limestone)
KTn	North Horn Formation
Kpr	Price River Formation
Ki	Indianola Group (undiff.)
Jm	Morrison Formation
Jt	Twist Gulch Formation
Ja	Arapien Shale

formation, the Price River. However, at none of the locality on the eastern front of the Gunnison Plateau, the Price River formation and the Indianola group occur together.

On the eastern front of the Gunnison Plateau, the North Horn formation overlies the Indianola, and the contact between the two is definitely unconformable as the deposition of the North Horn formation preceeded late Colorado and the Early Laramide orogenies. Though it is difficult to determine the exact relationship of the two formations with one another it is evident from the study of the other stratigraphic sections involving the Indianola and the North Horn formations that the contact is unconformable, the two formations being separated by an angular unconformity. Likewise the lower contact of the Indianola group undifferentiated with the Twist Gulch formation is non-conformable. The deposition of the Twist Gulch formation was followed by a period of non-deposition and consequently the Morrison formation is missing from the area. It was the erosional surface of the Twist Gulch formation over which the Indianola group undifferentiated was deposited. Therefore it is evident that the lower contact of the Indianola group undifferentiated with the Twist Gulch formation is unconformable.

At Wales, on the eastern front of the Gunnison Plateau, a complete section of the Indianola group undifferentiated is exposed. The Indianola and North Horn are separated by the intervening Morrison and the Price River formations. However, farther south, the section is not complete, and the Price River formation is completely missing and the Indianola is overlain by the North Horn formation (fig. 5).

The nomenclature, used in the figure 5 is changed because of revision of the pre-existing one by Speiker and Hardy (1949).

Figure 4, shows the general relationship of the Indianola with the overlying formations and a comparison between the two stratigraphic section exposed north and south of Axehandle Canyon.

The patchy occurrence of the Indianola group is in no way the original mode of its occurrence. When its fulviatile and flood plain environments of deposition are considered, it is very much apparent that the sediments comprising this formation were cast eastward as a thin blanket over a wide area. These deposits were subsequently subjected to orogenic movements (Laramide) to be followed by extensive and rapid erosion. The scattered and discontinuous outcrops of the Indianola group undifferentiated coupled with severe folding caused by the Early Laramide orogeny support evidence for an extensive and rapid erosion of the unit. The present patchy occurrences represent the left-over pockets of the Indianola on the post Early Laramide orogenic surface (Hunt, 1948).

Age and Correlation

Because of its undifferentiable nature, it is difficult to extend any correlation of the Indianola formations from differentiable localities to the eastern front of the Gunnison Plateau and hence the area of investigation. However, Speiker (1946, p. 126-130) suggested a Coloradoan Age for these sedimentary rocks. See Table 2 (in pocket).

Southwest of Manti, where the Indianola group is differentiated into 4 formations, Speiker (1946, p. 127-128), assigned the following ages to each of the recognizable and differentiable formations.

Units	Age
Six mile Canyon formation	Upper Coloradoan
Funk Valley formation	Upper Coloradoan
Allen Valley Shale	Middle Coloradoan
Sanpete formation	Early Coloradoan

PRICE RIVER FORMATION

Definition and Type Locality

Speiker and Reeside (1925, p. 445), applied the name Price River formation to a succession of sandstones, grit, conglomerates, and subordinate quantities of shale occuring between the Black Hawk and North Horn formations"in the canyon of Price River above Castlegate, Utah" (Speiker and Reeside, 1925, p. 445). The Price River formation at the type locality is divisible into two distinct members, a massive basal member originally defined by Clark (1928, p. 20) as Castlegate, prominent as cliff former, and an unnamed upper member which forms slopes rather than cliffs (Speiker and Reeside, 1925, p. 445).

"The Castlegate sandstone member is separated from the Upper member solely because of its cliff forming..." attitude, "which gives it great regional prominence..." (Speiker, 1946, p. 130), otherwise both the members show marked similarities to one another (Speiker, 1946, p. 130).

The thickness of the Price River formation at the type locality is approximately between 900 and 1000 feet (Gilliland, 1951, p. 17). The formation shows a textural gradient if traced from west to east. The western exposures of the Price River formations are characterized by coarse clastics; whereas the eastern exposures are much finer.

Distribution:

The Price River formation is exposed at various localities through out the Wasatch Plateau and in the areas both on the east and the west of the Wasatch Plateau. Outside central Utah, the most notable exposure occurs in the Book Cliffs, and the extension of the Castlegate sandstone member is recognizable as far east as the Utah-Colorado boundary.

Gilliland (1951, p. 17) reported the occurrence of the Price River formation at the south extremity of the Gunnison Plateau, in Long Ridge, west of Nephi, Utah, and at the northern exgremity of the Pavant Plateau.

The Price River formation is exposed along the west and northwestern front of the Gunnison Plateau. South of Mount Nebo, the Price River formation is seen forming high and very steep cliffs of the northern end of the Gunnison Plateau.

In the area of investigation, the Price River formation occurs in very limited exposures between Dry Canyon and Maple Canyon.

Lithology and Thickness

The Price River formation exposed in the area of investigation lacks any Castlegate member characteristics. Here the formation is mainly composed of massive conglomerate with some lenticular beds of sandstone, which measure 8 - 12 inches in thickness.

The conglomerate is composed of pink and white quartzite cobbles, which are rounded to sub-rounded and measure about 8 inches in diameter. Some of the cobbles measure more than 8 inches and attain a diameter as much as 12 inches, thus grading into the category of boulders according to the Wesntworth's Particle Size Classification Scale.

The cobbles and boulders are embedded in an argillaceous and course sandy matrix. The matrix at places tends to become purely sandy and very coarse.

The Price River formation which is rusty red in color weathers to various shades of brown color. The exposure of the Price River formation south of Dry Canyon although a conglomerate appears from distance as a steep cliff of sandstone, however, a close examination reveals the true nature of exposure (Hunt, 1949).

From the heterogeneous lithology, extreme variations in particle size, and the shape of unit, it is very much evident that the Price River formation, exposed in the area of investigation, is a fanglomerate deposit.

In the area of investigation the thickness of the Price River formation varies from nil to 550 feet. The measured thickness of the unit in the area is 550 feet.

Section of the Price River formation measured south of Dry Canyon.

Twist Gulch formation

Conglomerate, quartzite pebbles and cobbles ranging in size from 3 inches to 6 inches, dark limestone pebbles in the lower part, weathers to rusty brown, lenses of well cemented sandstone at various stratigraphic levels, particularly near the top . . . . 320 ft.

Conglomerate interbedded with sandstone, light brown to reddish brown, medium to coarse grained, weathers to rusty brown . . . . 28 ft.

Conglomerate, pebbles and cobbles varying in size between 5 inches to almost one foot, white, red, purple bended Quartzites, gray, grayish brown, and red sandstone, dark gray and black dense limestone pebbles in subordinate quantity. Sandstone lenses occur at various stratigraphic levels . . . . 202 ft.

Total thickness 550 ft.

Relation to Adjacent Formations

In the type area, the Price River formation occurs "between the Blackhawk formation and the former lower member of the Wasatch formation, now the North Horn formation" (Speiker, 1946, p. 130).

In the area of this report, the Price River formation unconformably overlies the Twist Gulch formation and conformably underlies the North Horn formation.

From informations accumulated, it is very much evident that there is a regional unconformity between the Price River formation and the older formations ranging in age from Precambrian to Coloradoan (Gilliland, 1951, p. 18). The following evidences support the presence of a regional angular unconformity between the older formations and the Price River formation. A belt of the Price River conglomerate is exposed near the southern end of the Gunnison Plateau. This belt belongs to a near source orogenic facies of the Price River, and is distributed "in a north-south belt extending at least from the Pavant Plateau to the southern Wasatch Mountains. This belt is bound on the west by folded rocks of the source area. Throughout this belt, the conglomerate of the Price River unconformably overlies older ...rocks" (Gilliland, 1951, p. 18).

In the area of investigation, the rocks belonging to the Indianola group undifferentiated are not found in contact with the overlying Price River formation. This fact supports the thesis that the Price River formation was deposited on an old erosional surface.

Age and Correlation

No precise correlation and age determination of the Price River formation has so far been attempted in the regions west of Wasatch Mountains.

The Price River formation exposed in the area of this report has no yielded any fossils. However, "the age of the Price River formation is shown by invertebrate fossils at the type locality to be late Montana. Elsewhere to the west, however, the coarse sediments of the formation appears to contain no fossils, and as it is traced westward, through the Gunnison Plateau and beyond, the question of age is becoming bothersome" (Speiker, 1949, p. 25).

Thus it is evident that the age determination and correlation of the Price River formation in the western regions of Utah in general and the Gunnison Plateau in particular is still in a state of flux.

However, Speiker (1949, p. 25), has suggested that the formation grows younger as it is traced toward the west, it is likely that the Price River formation exposed in the area of investigation represents a very late Montana age. This conclusion is suggested by the fact that the Castlegate Sandstone member is missing from the area, and the upper beds of the Price River formation intertongue with the overlying North Horn formation and finally appear to grade and merge into it. To the south of the area the boundary has not been determined.

In my opinion an age between Maestrichtian (upper most stage of Montana) and Danian can be assigned until some definite conclusion is reached. See Table 2 (in pocket). This seems to be valid when the intertonguing and intergradations between the Price River formation and the North Horn formations are taken into consideration.

CRETACEOUS AND TERTIARY SYSTEMS

NORTH HORN FORMATION

Definition and Type Locality

In the Wasatch Plateau, east of the area of investigation, Speiker and Reeside (1925, p. 448), recognized a formation above the Price River formation which was divisible into three distinct units, which they named as the Wasatch formation.

The three distinct units comprising this formation, are from bottom to top:

3. "An upper member of varicolored shale and sandstone"
2. "A middle member of fresh water limestone" defined as the Flagstaff limestone member.
1. "A lower member of sandstone, varicolored shale, conglomerate, and small amounts of fresh water limestone."

With the exception of the basal conglomerate, now the Price River formation, the unit number 1 (lowest member) has been re-named the North Horn formation (Speiker, 1946, p. 132-133). The North Horn formation is divisible into 4 distinct units in the type locality, the North Horn Mountains (T 5, 18; and 19 S., R. 6 E., Salt Lake Meridian), east of the Wasatch Plateau.

The four units as distinguished by Speiker (1946), in the type locality are from oldest to youngest:

"Unit 1. Shale, red, and variegated in upper part, gray in lower part, with interbedded buff and gray sandstone, and some limestone, the bedding very even and individual layers thin, lacustrine in origin; forms steep slopes and cut banks beneath limestone cliffs or flagstaff... 250 ft.

Unit 2 Shale, gray to variegated, with thin beds of fubb sandstone, in general irregularly bedded; flood plane deposits; forms gentle slopes .... 300 ft.

Unit 3 Shale, gray to black, sandstone, buff to light cream and gray, chiefly fine; some limestone, in very evenly bedded succession, layers generally not over 5 feet thick; mainly lacustrine; generally capped by resistant sandstone and forming shoulder or terrace with steep front slope .... 250 ft.

Unit 4 Shale, gray in lower part, variegated in upper; sandstone, buff to gray, mainly medium to fine but with conglomerate in places. Minor amounts of limestone; dominantly flood plain in origin; forms gentler slopes between Unit 3 and Price River formation ...... 850 ft."

1,650 ft.

"The North Horn formation in this part of the plateau thus represents an alternation between fluviatile and lacustrine conditions" (Speiker, 1946, p. 133).

Distribution

The North Horn formation is exposed throughout central Utah. The North Horn formation exposures are also reported from western Book Cliffs, north of Thistle (Baker, 1929), and Salina district (Speiker and Baker, 1929, p. 143-145) Gilliland (1951, p. 20) has reported the North Horn formation exposures in Long Ridge, the Pavant Plateau, the Valley Mountains, and in the Gunnison Quadrangle.

The North Horn formation is exposed extensively along both the fronts of the Gunnison Plateau thus forming most of the exposed sections of the plateau both along the western and eastern fronts. In the interior parts of the plateau, the North Horn formation is found exposed near the base of various canyons and their smaller tributaries.

In the area of investigation, the most extensive and complete exposure is found on either side of the mouth of Axehandle Canyon. Further north, additional basal strata of the North Horn formation add to the total thickness. The whole exposure "makes the body of the bulky promontory known as the 'Point of the Mountain' (Speiker, 1949, p. 29).

Lithology and Thickness

Of all the formations exposed in the area of investigation, the North Horn formation is the most diverse. Here it is composed of a variety of continental deposits. These deposits range from very coarse clastic rocks to lacustrine limestones (Hunt, 1948, p. 36). However, the coarse clastic sediments are the dominant constituents of the North Horn formation, particularly in the northern part of the area of investigation.

The North Horn formation shows rapid variations in lithology, both veritcally and laterally. The beds which are exposed to the north of Rock Creek are considerably different from those exposed to the south of Dry Canyon, both in lithology and thickness.

Between these two occurrences is another exposure of the North Horn formation, which appears to be transitional between northern and southern exposures. This exposure of the North Horn formation is characterized by the occurrence of metals and carbonaceous or coaly materials. It is noteworthy that exposures of the North Horn formation both north and south of the area lack these metals and coaly materials except in Coal Canyon where the North Horn formation is coal bearing. A detailed discussion concerning the occurrence of these metals will be taken up in thelater part of this report.

In the area of this report the North Horn formation can be conveniently divided into two units, (1) coarse clastic sedimentary rocks, and (2) fine clastic sedimentary rocks.

"In the area to the north of Rock Creek, the development of"... Unit 1 "is very great" (Hunt, 1948, p. 36). Here one can observe the extreme diversities and their occurrences so characteristically displayed by the North Horn formation. The deposits in this part are dominantly coarse clastic sedimentary rocks, as is evident from the following section which was measured at the mouth of Axehandle Canyon by Hunt (1948) and later in 1966 by the present writer. The thickness figures differ slightly from those reported by Hunt (1948, p. 36).

Flagstaff Limestone

North Horn formation:

Unit 1. a. Massive to thick beds of cross-bedded

conglomerate, occasionally containing
lenses of coarse-grained sandstone .... 496 ft.

b. Thick alternating beds of sandstone and
algal limestone. Conglomerate mostly
occurring as lenses at the base of
medium to coarse-grained sandstone .... 1202 ft.

The sandstone beds exposed in this section are loosely cemented to friable. The color varies from tan brown to gray. They are mainly composed of sub-rounded to nearly rounded, medium to coarse sized grains (Hunt, 1948, p. 36). The conglomerates, which are exposed at the base of the section and forms steep cliffs on either side of the mouth of Axehandle Canyon, are extremely thick bedded to massive and display perfect cross-bedding. The constituent pebbles are either dark colored limestone or light colored quartzite, embedded in a matrix of medium to coarse quartzose sand. The pebbles show various degrees of roundness, mostly faceted or sub-rounded pebbles occur. Both the conglomerates and sandstones of this section weather to various shades of brown and gray colors.

Interbedded with conglomerates and sandstones are the limestone beds, which are gray and tan in color. These limestones are extremely hard and dense, varying in texture from non-crystalline to crystalline. Sand grains, mostly quartz, occur scattered throughout the beds. At places within the measured section contorted and bracciated beds of limestone occur indicating a pre-lithification disturbance and post-lithification fracturing. The limestone beds in general are irregular and the bedding plane show undulatory surfaces.

The limestone strata of the North Horn formation are characterized throughout the area by the occurrence of "algal balls". The size of these balls vary from half inch to more than a foot in diameter. At certain levels of the section, these concentrate to such quantities as to give rise to what can appropriately be termed as "algal ball conglomrates". In such conglomerates a matrix is completely lacking (Hunt, 1948, p. 38).

Eardley suggested the term 'ooids' for these algal balls. He suggested that these structures may have "formed in a lake impounded in a closed basin formed by coalescing of alluvial fans" (Hunt, 1948, p. 39).

Insignificant amount of shale occurs in this section. The siltstones, which constitute the bulk of the North Horn formation south of Dry Canyon, are also present in subordinate quantities. The maximum thickness of siltstone beds measured in this section is 76 feet.

South of Dry Canyon the entire lithology so characteristic of northern part of the area, "changes to gray shale and calcareous siltstones" (Speiker, 1949, p. 29) with subordinate quantities of limestone occurring at various stratigraphic levels.

It is observed that the North Horn formation shows a rapid variation in facies within a span of 10 miles. In Wales Canyon (not in the area of investigation), "the North Horn formation shows facies which are commonly prevalent in the central Wasatch Plateau and is approximately 250 feet thick. Here it contains beds of limestone oil shales, and coal. Below the limestone beds more variegated shales, limestones, siltstones, sandstones, and red shales occur (Speiker, 1949, p. 29).

This facies is not observed in Axehandle Canyon though the distance involved is about 5 miles.

If only lithologic characters are considered it would be very difficult to correlate the various facies of the North Horn formation, which are present within a span of 10 miles.

The increase in thickness of the North Horn formation in this region is mainly due to the exposure of additional beds, which are missing in Axehandle Canyon area and farther south. It is estimated that at least 1000 - 12000 feet of additional strata are exposed in the "bulky promontory" area.

Hunt (1948, p. 39-40) suggested that the great thickness attained by the North Horn formation in the locality now referred to as "the Point of the Mountain", is due to differential subsidance of a leveled surface during the deposition of the North Horn formation. The subsidance was more rapid to the north.

The total thickness of the North Horn formation measured in the area of investigation is 1698 feet.

Section of the North Horn formation measured at the northern wall of Axehandle Canyon near its mouth.

	Feet	Inches
Conglomerate, massive lenticular, cross-bedded, lenses of sandstone, friable at the top. The sandy matrix tends to become clayey in theupper parts. The conglomerate comprises of dark colored limestone pebble measuring 1 - 2 inches in diameter	392	0
Sandstone, gray, evenly bedded, weather by the process of exfoliation	12	0

	Feet	Inches
Siltstone, compact and well cemented, shows lenticular bedding	76	0
Conglomerate, variegated, sandstone and quartzite pebbles abundant limestone pebbles rare	16	0
Sandstone, tan colored, angular to sub-angular grains ..	2	6
Limestone, tan to gray, dense, non-crystalline to almost lithographic, a few algal balls or 'ooids' occur scattered	84	0
Conglomerate, lenticular, mostly limestone pebbles ranging in size from $1\frac{1}{2}$ inch to 2 inches in diameter	4	0
Sandstone, mottled, losely cemented to almost friable ..	4	0
Limestone, nodular fresh surface tan to white, weathers brown	10	0
Limestone, gray, massive, occassional algal balls or 'ooids'	29	6
Conglomerate, tan to brown and black limestone pebbles, lenticular sandstone present	8	3
Sandstone, tan to brown, medium grained, contorted	43	3
Limestone, non-crystalline to almost lithographic massive and fractured	17	0
Sandstone, medium to coarse, cliff forming similar to one exposed in Coal Canyon	21	0
Shale, bluish-gray, limonite stains, occasional occurrence of pyrite crystal	4	6
Sandstone, tan to gray, medium to coarse grained, contorted, conglomerate at base	34	6

	Feet	Inches
Limestone, tan to gray, finely crystalline massive, weathers to various shades of brown	26	0
Sandstone, tan to gray, coarse grained albase, middle portion brown and calcareous, becoming friable near top .	36	9
Limestone, dark gray, massive, noncrystalline becoming lithographic	14	3
Sandstone, tan, fine grained	10	0
Sandstone, tan to gray, medium grained	4	0
Limestone, tan, nodular, weathers yellow	14	0
Sandstone, gray and dark tan, fine grained, massive ..	37	0
Limestone, tan marly and concretionary	3	0
Conglomerate, dominantly comprised of quartzite pebbles	4	0
Sandstone, tan to brown, fine to medium grained	28	0
Limestone, gray, thin lenticular, conglomerate at base	26	0
Sandstone, gray, medium to coarse grained, angular to subangular	5	0
Limestone, tan, large algal balls or 'ooids' varying in size from 2 to 6 inches. Massive	20	0
Sandstone, gray, coarse grained, cross-bedded	16	0
Limestone, gray, soft	14	0
Sandstone, gray, medium to coarse-grained	16	0
Limestone, gray, tan, massive, characterized by algal balls varying in size ½ to as much as 1 foot	49	0
Sandstone, tan, loosely cemented	20	0

	Feet	Inches
Sandstone, grayish white to white, weathers to brown, conglomeratic at base	30	0
Limestone, tan, conglomeratic at base	24	8
Limestone, gray, algal balls present varying in size from 1 to 2 inches	11	4
Sandstone, tan, forms cliff	90	0
Limestone, gray nodular	15	0
Conglomerate, black limestone pebbles abundant, quartzitic pebbles rare, lenticular	5	0
Sandstone, gray, slabby to thin-bedded	25	0
Limestone, dark-gray, extensively brecciated	4	6
Sandstone, tan to gray, coarse grained, angular to sub-angular, poorly cemented to friable	4	0
Sandstone, gray, medium grained	4	0
Grit, bottled, weathers yellow	12	0
Conglomerate, lenticular	3	0
Sandstone, tan to gray, medium grained, calcareous, massive	15	0
Limestone, tan to gray, grains of quartz scattered	86	0
Conglomerate, dirty buff, weathers pink	5	0
Limestone, gray, dense	7	6
Conglomerate, dark limestone pebbles and light colored quartzite pebbles	25	0
Limestone, gray, dense massive	25	0

	Feet	Inches
Sandstone, gray, weathers brown	54	0
Shale, pink, sandy, quartz grain abundant	4	0
Sandstone, gray, medium to coarse grained, cross-bedded, weathers to black............................	13	0
Limestone, non-crystalline to finely crystalline, massive	21	0
Limestone, tan to cream colored, dense	45	0
Sandstone, gray, fine-grained weathers to brown	38	0
Limestone, tan, dense	62	0
Sandstone, grayish brown, medium grained	20	0
Limestone, dark gray, weathers yellow	3	0
Shale, gray, granular	7	6
Sandstone, gray, medium grained, angular to sub-angular, forms the last cliff separating the North Horn formation from the Flagstaff formation (Limestone)	12	6
Total thickness	1,698	6

Relation to Adjacent Formations

In the type locality the North Horn formation occurs between the underlying Price River formation and the overlying Flagstaff limestone. In areas lying to the south of the area of investigation, both the upper and lower boundaries of the North Horn formation have been arbitrarily determined. Gilliland (1951, p. 23), fixed the upper boundary of the North Horn formation of the Gunnison Quadrangle on arbitrary basis.

In Mellor Canyon which lies at the southwestern end of the Gunnison Plateau, the lower boundary of the North Horn formation is gradational with the Price River formation, while the upper boundary is gradational with the overlying lacustrine Flagstaff Limestone. However, in Six mile Canyon near Sterling, Utah, the overlying Flagstaff Limestone is seen truncating the underlying North Horn formation (Speiker, 1946, p. 133).

In the thesis area, both the lower and the upper boundaries are exposed. The contact of the North Horn formation with the underlying Price River formation is conformable. Similarly the contact of the North Horn formation with the overlying lacustrine Flagstaff Limestone is conformable. Between Axehandle Canyon and Rock Creek and in the north of this area, a 20 foot cliff forming sandstone bed separates the North Horn formation from the overlying Flagstaff formation (Limestone). The contact is placed along the upper surface of the sandstone bed.

An angular unconformity separates the North Horn formation from the underlying Twist Gulch formation, wherever the Price River formation is lacking or not exposed. Thus indicating removal of the Indianola and the Price River formations before the North Horn formation was deposited.

Between Maple Canyon and Dry Canyon, both the lower and upper contacts of the North Horn formation are conformable as well as gradational. The boundaries are fixed on a purely lithologic basis. Here the lower contact of the North Horn formation is placed on the top of the Price River conglomerate. Whereas the upper contact of the North Horn formation is placed where silt and sandstone strata give way to first persistant beds of limestone of the Flagstaff formation. Farther south, near Maple Canyon, the Price River conglomerate pinches out and the North Horn formation unconformably overlies the Twist Gulch formation.

Age and Correlation

On the basis of faunal evidences, collected from the type locality, Speiker (1946, p. 135) has conclusively demonstrated that the North Horn formation embodies the "passage from Cretaceous to Tertiary", consequently the age of the North Horn formation is transitory between the latest Cretaceous and the earliest Paleocene.

In the area of this report no fossils were found. The age determination and correlation of the North Horn formation is thus exclusively based on the stratigraphic evidences. As both the upper and lower contacts of the North Horn formationare exposed in the area of this report, it is assumed that the formation has about the same age as the North Horn formation at type locality, and hence is correlatable "in some parts with the Lance and the Fort Union formations of the northern planes; and with the Ojo Alamo, the Puerco, and the Torrejon formationof the San Juan Basin" (Speiker, 1946, p. 135).

TERTIARY SYSTEM

FLAGSTAFF FORMATION (LIMESTONE)

Definition and Type Locality

The Flagstafff limestone, a former member of the Wasatch formation, was named by Speiker and Reeside (1925, p. 445-449) from Flagstaff Peak in the southern Wasatch Plateau. It was included as a member in the Wasatch formation mainly because of being considered "to be a lacustrine phase between flood-plain deposits of Wasatch age" (Speiker, 1946, p. 135). However, the lower member, now the North Horn formation is not considered of Wasatch age and the Flagstaff limestone is known to show greater affinities to the Green River formationthan the Wasatch formation, an age as well as a nomenclature revision became inevitable. The Flagstaff formation (limestone) is extensively developed over a large region, and shows a great degree of persistance and general consistancy on a regional scale, thus warranting the revision of the existing nomenclature. Consequently, the Flagstaff Limestone member was elevated to formational rank (Speiker, 1946, p. 135).

Gilliland (1949, p. 70) used the term 'Flagstaff Formation' for the western extension of the Flagstaff limestone. He considered the term Flagstaff limestone inappropriate to describe the unit exposed in the area west of Seveir Valley. Here the 'Flagstaff Limestone' is not a homogeneous formation. It contains considerable amounts of sandstones and conglomerates.

In the area of investigation, the Flagstaff limestone shows a greater degree of homogenity. The shale and sandstone constitute an insignificant amount of the total thickness exposed in the area. The calcareous facies dominates and the clastic facies are so insignificant that the writer does not think it to be completely appropriate to extend Gillilands nomenclature to the area of this report. Consequently the term 'Flagstaff limestone' is retained besides using Gilliland's latest term "Flagstaff formation".

Hunt (1948) who originally described the geology of this area used the term Flagstaff limestone as coined by Speiker and Reeside (1925, p. 448-449) and later revised by Speiker (1946, p. 135).

Distribution

The Flagstaff limestone is extensively developed in the Wasatch Plateau, the Gunnison Plateau, the Valley Mountains, the Long Ridge, and the Pavant Range. It is known to crop out in the area north to the Brook Cliffs.

The Flagstaff limestone is easily recognizable in all localities where it is exposed. It's grayish white color and cliff forming characters make it as one of the most distinct formations of the area of this report. In the words of Speiker "the Flagstaff limestone is not only prominent, but it is also useful, in its regional persistence and general consistency, as a marker unit, a steady and reliable guide, running solidly and conservatively through the shambles of lithologic originality indulged by its fellow formation. Without Flagstaff formation (limestone) for example, the stratigraphy of the Gunnison Plateau would be difficult, and locally perhaps impossible to work out..." (1949, p. 31).

On the western side of the Wasatch Plateau, the Flagstaff formation (limestone) crops out in long continuous ledges mostly capping the higher parts of the plateau. The formation sweeps down along the Wasatch Monocline, and passes under the alluvium of the Sanpete Valley which lies to the west.

In the area of this report, the Flagstafff limestone occurs continuously near the crest of the plateau front. The Flagstaff formation (limestone) crops out on the outlying hills along the base of the eastern front. These outlying hills, composed mainly of the Flagstaff formation (limestone), are landslide or slump blocks of the 'Torreva' type.

The Flagstaff limestone serves as an important formation in the area of this report and is of considerable help in working out the stratigraphy of the area.

Lithology and Thickness

In the area of investigation the unit is mainly composed of limestone, with subordinate amounts of sandstones and shales occurring at various stratigraphic levels.

The limestones vary from finely crystalline to lithographic in texture. The unit shows a variety of colors. The dominant color is yellowish gray, however, dark gray, brown, tan, black, or even white colored limestone strata occur at various stratigraphic levels. Calcite inclusions and algal balls occur scattered throughout the formation, however, the algal balls are more abundant in the lower strata of the formation. Dark gray to black limestones are fossiliferous and contains a variety of fresh water molluscans and ostracodes of Paleocene and Eocene ages.

Thin beds of calcareous shale are interbedded with limestone beds. However, where present as thick beds, show blocky structure, the shales are dense and dark gray in color. The sandstones which are tan and gray in color and medium to coarse grained in texture, show great affinities to the sandstones of the North Horn formation, pointing to the continuation of the conditions established during the development of the North Horn formation. The sandstones and shale strata are confined to lower part of the formation.

The Flagstaff limestone, though gives the appearance of being well bedded, is however, irregularly bedded and individual strata cannot be traced laterally over a distance of 200 feet. The strata show a prevalent tendency of pinching out in either direction. More undulatory and irregular bedding is observed in places where nodular (algal?) limestone is present.

On the basis of lithology the Flagstaff formation (limestone) can only be differentiated into three types which are not traceable over distances of more than 200 feet. These types are repeated at various stratigraphic levels, and lithologically they represent three kinds of limestones.

Lithographic Limestones

Finely crystalline Limestone

Nodular limestone with algal balls.

Gilliland (1951, p. 26-30) differentiated the Flagstaff limestone (Flagstaff formation as termed by him while describing the geology of the Gunnison Quadrangle) into 5 different units. This differentiation is mainly based on the lithologic characters. The type locality for Gilliland's units is the Valley Mountains. Basically he recognized 4 distinct facies of the Flagstaff limestone which he designated as:

1. "Valley Mountain Facies
2. Fayette facies
3. Willow Creek facies
4. Gunnison Plateau facies"

The Valley Mountain facies shows the maximum development of thickness as compared to the others as mentioned above. Gilliland (1951, p. 26) divided the Valley Mountain facies into five units. The "Unit A" which is the basal unit..." mainly consists of yellow and gray, dense to finely crystalline, massive, fossiliferous limestone with small amounts of arenaceous limestone, a few brown sandstone lenses in the lower part and gray shales" (Gilliland, 1951, p. 26-27).

In the opinion of the writer, Gilliland's "Unit A" shows greater affinities to the Flagstaff formation (limestone) of the area of investigation and hence the Gunnison Plateau facies of the Flagstaff formation is roughly correlatable with the "Unit A" of the northern Valley Mountain facies of the Flagstaff formation (limestone).

The Flagstaff formation (limestone) in the area of investigation weathers to sharply angular fragments which vary in size between 2 to 3 inches. These fragments form very steep talus slopes along the entire exposure of the Flagstaff formation (limestone) on the eastern front of the Gunnison Plateau.

The measured thickness of the Flagstaff formation (limestone) in the area of investigation varies between 350 and 430 feet.

Section of the Flagstaff formation (limestone) measured near the top of northern wall of Axehandle Canyon at its' mouth.

	Feet	Inches
North Horn formation	1698	6±
Limestone, gray, finely crystalline to non-crystalline, dense and hard	2	6
Sandstone, medium grained, angular to sub-angular, dense and well cemented	5	6
Limestone, grayish white to gray, abundant quartz inclusions massive, dense, and hard, breaks with conchoidal fracture	100	
Shale, gray, granular, calcareous	12	9
Limestone, gray to dark gray at places, non-crystalline to almost lithographic forms cliff, algal balls at base	54	6
Shale, gray, calcareous	35	6
Limestone, grayish white to gray, massive in lower parts and contains algal balls nodular near top, weathers to yellow	50	6
Limestone, gray to tan, mostly argillaceous, fossiliferous near top	53	
Shale, brown, granular and calcareous	18	

	Feet	Inches
Limestone, tan, dense to lithographic speckeled with small angular smokey quartz grains	18	
Total thickness	350	3

Relation to Adjacent Formations

In the area of this report the Flagstaff limestone overlies the North Horn formation. The contact is both conformable and gradational. In the northern part of the area, near Axehandle Canyon, the top of the North Horn formation and the bottom of the overlying Flagstaff formation (limestone) is drawn at the base of a prominent sandstone cliff, making unit, however, in the southern part the contact is decidedly gradational.

The Flagstaff formation (limestone) is overlain by the Colton formation. The contact, though conformable is very sharp, being located at the top of the Flagstaff formation from where a gentle slope starts marking the base of the Colton formation. The steep cliffs of the Flagstaff limestone abruptly give way to gentle slopes formed by the weathering and erosion of comparatively weaker shales of the Colton formation.

Age and Correlation

The exact age of the Flagstaff formation (limestone) is far from being settled. The quote is self explanatory. "The early considera- tion of the Wasatch formation of central Utah as lower Eocene and the resulting assignment of most fossils found in the Wasatch strata to that age has presented numerous difficulties to recent workers attempting the ages of the several formations now known to comprise the former Wasatch" formation. "The long range sustained by many fresh-water species further complicates any age determinations" (Gilliland, 1951, p. 32).

While discussing the age and correlation of the North Horn formation, it was pointed out that the North Horn formation embodies the "passage from Cretaceous to Tertiary", consequently the age of the North Horn formation is transitory between latest Cretaceous and earliest Paleocene. This, transitory age is substantiated by the vertebrate fossils which occur in the lower strata.

From the general relationship of the North Horn and the overlying Flagstaff formation (limestone) it is evident that the deposition of the Flagstaff formation (limestone) followed the deposition of the North Horn formation without any apparent lapse of time (at least in the area of investigation, where the contact between the North Horn and the overlying Flagstaff is transitory and no stratigraphic break is discernable). On the basis of this relationship and the presence of faunal suit in the Flagstaff formation (limestone) of the central Wasatch Plateau, suggesting an age older than Eocene, it is evident that the age of the Flagstaff formation (limestone) can be placed somewhere between middle and upper Paleocene(?). See Plate 2 (in pocket).

Gilliland (1951, p. 32), while carrying out investigations in the Gunnison Quadrangle, collected a number of fossils from the Flagstaff formation (limestone). However, none of these fossils furnishes a definite evidence regarding the exact age of the formation under discussion.

On the combined basis of paleontology, regional, and local stratigraphic relationships, the Flagstaff formation (limestone) can be assigned to a Tiffian and Clarkforkian age, late Paleocene, and can be correlated with the Fowkes formation of the southwestern Wyoming and the uppermost Fort Union strata of the northern Great Plains (wood, et. al., 1941, pl. 1). The same age and scheme of correlation was supported by Gilliland (1951, p. 16 and 24) for the Flagstaff formation (limestone) of the Gunnison Quadrangle.

COLTON FORMATION

Definition and Type Locality

The Colton formation was formerly considered as the upper member of the Wasatch formation by Speiker and Reeside (1925, p. 449). Later in 1946, Speiker, while revising the former Wasatch formation elevated the former upper member of the Wasatch to formational rank giving the name Colton formation (Speiker, 1946, p. 139). At the type locality north of Colton the formation overlies the Flagstaff formation (limestone) and underlies the Green River formation.

Distribution

As compared to other formations which are exposed in the area of investigation, the Colton formation is rather restricted in its regional distribution. "The known distribution of the Colton formation is restricted to the northern and western margins of the Wasatch

Plateau, the body of the Gunnison Plateau, and the south eastern margin of the Valley Mountains (Speiker, 1949, p. 34). In the Wasatch Plateau, the Colton formation is only exposed at the base of the Wasatch Monocline and in the Joe's Valley graben at the head of the Dragon (Speiker, 1949, p. 34). In other portions of the Wasatch Plateau, the Colton formation has been eroded away.

In the area of investigation, the Colton formation shows a greater areal extent than any of the other formations exposed. The Colton formation "caps the interfluviatile divideds from the "eastern" front of the plateau westward until the Green River formation conceals it" (Hunt, 1948, p. 52-53).

Lithology and Thickness

The dominance of shale and limestone characterizes the Colton formation. Sandstone is prevalent near the base of the formation. Infact, it is hard to distinguish these lower sandstone beds from those which are present in the upper part of the Flagstaff formation (limestone).

In the type locality the Colton formation is composed mainly of red shale and sandstone. The sandstones weathers brown (Speiker, 1949, p. 34).

In the area of this report, shale makes up the bulk of the formation and is hard and shows blocky structure. The shale is red, brown and gray in color. This color pattern is absent in the type locality which lies to the north east of this area some 40 miles away. Farther south in the Gunnison Quadrangle, the shale of the Colton formation shows a wider spectrum of colors. Here the shale is grayish-green, green, chocolate-brown, and purple, giving rise to a more or less variegated series (Gilliland, 1951, p. 34).

The limestones, which constitute the subordinate quantity of the Colton formation, show a greater range of colors. They vary in color from white to dark gray. However, the light gray varieties form the bulk of limestone contents of the whole formation. These limestones vary in texture from finely crystalline to lithographic, and are tracable over a long distance without any change in their lithology.

Sandstones which are present in smaller amounts, mainly represent channel deposits and consequently show typical lenticular bedding which pinches out laterally.

Hunt (1949, p. 53) divided the Colton formation into three distinct units, which the present writer found helpful in working out the lithology of the Colton formation and identifying it from the overlying and underlying formations. These units are:

"3. Shale, red and gray, with a few thin beds of limestone. Many channel sands exposed	222.11
"2. Alternating beds of shale and limestone	398.7
"1. Sandstone, with a few relatively thin beds of shale and limestone"	215.5
Total thickness	836.11

In the "Unit 2" thin "streaks" of coal occur, the thickest ones measures about 3 inches. "Unit 1" and "2" are separated by a sandstone bed which becomes shaly at top. The sandstone measures 112 feet.

The contact of the Unit 1 with the Unit 2 is placed at the top of this sandstone. A 164 feet thick bed with alternating beds of shale and limestone separates "Unit 2" from "Unit 3". The top of this bed, with alternating beds of Shale and limestone, marks the contact with Unit 3.

The measured thickness of the Colton formation is 836 feet. This thickness is fairly constant through out the area. The following section, which was measured near the head of the south fork of Axehandle Canyon, gives a detailed description of the lithology of the Colton formation.

Section of the Colton formation near the head of the south fork of Axehandle Canyon.

	Feet	Inches
Flagstaff formation (limestone) at Base, contact conformable	300 - 420	
Shale, red, soft, and blocky at base becoming tan in color and clayey in upper part	54	6
Sandstone, grayish brown, medium to fine grained angular to subangular grains, slightly calcareous	2	6
Shale, red, and friable	10	
Limestone, argillaceous, surface mottled, clear quartz grains scattered throughout bed	4	5
Shale, gray to dark-gray, clay-like slightly calcareous in lower parts, sand in upper parts.	2	

	Feet	Inches
Sandstone, tan to brown, coarse grained, sub angular to sub-rounded grains. Lenticular, pinches out in either direction	4	6
Shale, dark-gray to black, carbonaceous matter calcareous to argillaceous limestone in upper part	12	
Shale, dark-gray to black, carbonaceous matter present, thin beds of bituminous coal	14	
Sandstone, tan, mottled, medium grained, angular to sub-angular grains, grades into shale upward	112	
Shale, gray granular and sandy, fossiliferous	55	
Limestone and shale, thinly and alternately bedded bedding mostly even. Highly fossiliferous	32	10
Shale and limestone, alternating beds, thinly bedded rusty brown to maroon shales, light-gray to white limestone, weathering to tan, brown and rusty brown	136	6
Shale, brown and light red, granular, a 3 inch thick bed of bituminous coal at base	4	3
Limestone and shale, limestone dominant thin alternating beds of shale occur with comparatively thicker beds of limestone, mostly gray, tan, brown, and red in color	170	
Shale, gray, thinly bedded	10	

	Feet	Inches
Limestone, gray to dark gray, dense, almost lithographic, weathers to black color	1	6
Shale, gray, hard and compact in lower parts, soft in upper parts	20	
Sandstone, gray, fine to medium grained, angular to sub-angular, micaceous	6	
Shale, gray, blocky	26	
Sandstone, gray and tan, fine grained micaceous	11	
Limestone, gray to green, dense and hard in lower part becoming argillaceous in upper part..	8	
Limestone, dark gray to black lithographic		6
Sandstone and shale, brown and gray hard, micaceous .	13	2
Limestone, grayish white, almost lithographic	1	
Shale, gray and brown, hard	2	
Shale and Sandstone, shale gray to brown, hard, sandstone gray to dark gray, fine grained	15	6
Limestone, light gray and white, lithographic weathers to dark gray	3	
Shale, gray, hard granular, with a two feet limestone bed in between	27	3
Limestone, bluish-gray, hard	2	
Shale, gray and brown	9	10
Sandstone, gray, lenticular	1	
Shale and sandstone, gray and brown hard weathers to rusty brown	9	

	Feet	Inches
Sandstone, grayish-green, well cemented, angular and equigranular	6	6
Shale, gray, hard, weathers to greenish-gray and dark gray	16	8
Sandstone, brown and gray, friable	7	
Shale, brown and gray, sandy, hard	3	
Shale, brownish red, hard, micaceous	10	
Sandstone, gray, red and brown, fine grained, micaceous	12	
Total thickness	836	11

Fresh water mollusc occur abundantly near the top of the Unit 1. However, these are porrly preserved. Among the identifiable ones are several species of <u>Unio</u> and <u>Helix</u>. Reeside identified the Colton fauna "as member of the traditional Wasatch fauna" (Speiker, 1946, p. 139). Besides <u>Unio</u> and <u>Helix</u>, which belong to class Pelecypoda and Gasteropoda respectively, Arthropods are represented by Ostracods which occur in abundance. Gilliland reported the abundant occurrence of Ostracods in a limestone bed about 1 to 5 feet thick near the base of the formation.

Vertebrates are represented by bone fragments, teeth, and scales of fish. However, these occur sparingly in the limestones. Gilliland reported the occurrence of ganoid scales from the Colton formation in the northern Valley Mountains. The scales were tentatively identified to be from fish belonging to the family Lepidosteidae (Gilliland, 1951, p. 34).

Relation to Adjacent Formations

In the area of this report, the underlying Flagstaff formation (limestone) which forms steep cliffs is conformably succeeded by the Colton formation. The steep cliffs give way to gentler slopes marking the contact between the Flagstaff formation (limestone) and the Colton formation.

The upper contact of the Colton formation is like-wise conformable. "At the upper boundary of the "Colton formation... the red shale contrasts strikingly with the nearly white beds of the Green River formation" (Hunt, 1948, p. 54). Therefore the Colton - Green River contact was placed at the top of the highest occurring bed of red shale.

In areas other than the area of this report the Colton formation has been discovered to intertongue with both the underlying Flagstaff formation (limestone) and the overlying Green River formation (table 2). Speiker (1946, p. 139) reports abundant evidence of intertonguing of the Colton formation with both the Green River and the Flagstaff in the western districts of the central Utah. In large parts of the Gunnison Plateau the Colton formation is apparently absent (Speiker, 1946, p. 139).

From the above statement, it is evident that recognition of the Colton formation as well as its development in the area of this report is localized, and therefore "the red strata of the Colton represent "local occurrences of a different environment during the deposition of part of the Green River" (Hunt, 1948, p. 54).

Age and Correlation

The fossil collections from the Colton formation have not yielded any species found either in the North Horn formation or the Flagstaff formation (limestone). Therefore it is evident that the Colton strata are of different age than the North Horn and the Flagstaff formations. This leads to the conclusion that the Colton formation is of Eocene age. However, so far no conclusive paleontological evidence has been gathered either to prove the Colton formation of Eocene age or to disprove that it is not of Eocene age (Speiker, 1946, p. 139).

The stratigraphical evidences are likewise dubious and uncertain. No success is achieved in attempts which have been made so far to solve this difficult problem. Therefore in absence of a definite evidence the only conclusion about the age of the Colton formation which can be drawn is that it is of Eocene age.

The Colton formation is partially correlatable with the Knight formation of the southwestern Wyoming, and with the Sand Coulee and the Gray Bull of the Big Horn Basin, Wyoming (Wood and other, 1941, plate 1).

GREEN RIVER FORMATION

Definition and Type Locality

The term Green River was first used by Hayden in 1869 to describe a new group of rocks from a locality lying a little east of Rock Spring station in Wyoming (1869, p. 90).

At the type locality, the Green River formation "is composed of thinly laminated chalky shales.... They are evidently of purely fresh-water origin, and of middle tertiary" (Tertiary) " age. The layers are nearly horizontal, and, as shown in the Valley of Green River, present a peculiarly banded appearance" (Hayden, 1869, p. 90-91).

Since 1869, these laminated chalky shales have been studied, and described "over large areas of Wyoming, Colorado, and Utah (Gilliland, 1951, p. 38).

Refinement of the geological age, stratigraphic relationships, and correlation of the Green River formation has been achieved by many early workers. Among these workers Cope (1874, p. 435-444), Peale (1876, p. 148), King (1876, map 2), and Bradley (1930, p. 87-110, and 1931, p. 1-56) have contributed a great deal of valuable information concerning the Green River formation.

Distribution

The Green River formation is extensively distributed and its distribution roughly coincides "with the two interior basins, separated by the Uinta Mountains, in which the deposition took place" (Gilliland, 1951, p. 38). These two interior basins were named as Gosiute Lake in north and Uinta Lake in south by King (1878, p. 446) and Bradley (1930, p. 88) respectively.

The Gosiute Lake (King, 1878, p. 446) occupied the southwestern Wyoming, whereas the southern basin of Uinta Lake (Bradley, 1930, p. 88) extended as far as east-central Utah and northwestern Colorado. The western limit of the Uinta Lake was placed by Bradley (1930, p. 88) half way between Price and Provo, however Gilliland (1951, p. 38) described the Green River formation's outcrop from southern Utah as far as Gunnison Quadrangle. "The recognition of" the Green River strata in the Gunnison Quadrangle extends the limits of Bradley's Uinta Lake (1930, p. 88) to as far southwest as 75 miles (Gillilands, 1951, p. 38).

"The Green River formation is absent from the top of the Wasatch Plateau as is the Colton formation, but is exposed at the low lying cuestas at the base of the Wasatch Monocline in the Sanpete Valley" (Hunt, 1948, p. 61). It is extensively exposed in the Gunnison Plateau particularly the central part of the plateau, and in the Cedar Hills.

In the area of this report the Green River formation crops out on the highest points of the plateau and forms the main east-west drainage divide (Hunt, 1948, p. 61).

Lithology and Thickness

In the area of this report, the Green River formation is characterized by two types of lithologies i.e., limestones and shales. The entire formation consists of very evenly and thinly bedded lacustrine clastics and non-clastics rocks chiefly limestone and shale.

The limestones present in the Green River formation show very faint shades of gray and tan color. However, the whole formation is characterized by a white color on weathered surfaces. These weather to slightly yellowish hue. These limestones are dense, hard, finely crystalline to non-crystalline and thinly bedded. Interbedded with these limestone beds are beds of oolitic limestone.

In some of the dense and finely crystalline limestone beds, are included small and sparkling grains of quartz.

The shale varies from white to light-gray in color and are very hard and show blocky structure. The blocky characteristic of these shales is not confined to any particular stratigraphic level and is repeated throughout the section (see section on p. 60).

The abundance of smoky quartz grains gives an overall spotted appearance to the rock. The abundance of quartz grains in the Green River formation is indicative of the prevalence of explosive volcanic activity contemporaneous with the deposition of the Green River formation. In fact, in the upper part or near the top of the formation, lava flows of felsitic composition occur. These flows are massive, consequently no flow structure is discernable. The felsite is composed of a light-gray aphinitic ground mass, in which occur numerous small black phenocrysts of possibly a ferromagnesian mineral, most probably hornblende and biotite.

Gilliland has reported green tuff beds from the northern limits of the Gunnison Quadrangle. Another tuff bed with abundant biotite crystal overlies the greenish gray shales about 2 $\frac{1}{2}$ miles east of Gunnison (1951, p. 39). It is suggested that the tuff beds may correlate with some of those which were observed by Faulk (1948) in the Green River, north of Manti (Gilliland, 1951, p. 39).

In the Gunnison Quadrangle three distinct lithologic zones of the Green River formations are recognizable.

(1) "A basal zone of limestone or limestone and shale".

(2) "A middle zone of green or greenish-gray shale, and"

(3) "an upper zone of limestone, that is usually yellow and thinly laminated to massive" (Gilliland, 1951, p. 39).

The zone 1 is least developed in the Gunnison Quadrangle and is locally missing in the Valley Mountains and in larger parts of the eastern position of Quadrangle. Whereas the two higher zones give rise to numerous cuestas and hogbacks (Gilliland, 1951, p. 39). These cuestas and hogbacks are observed in between Fayette and Redmond. The more resistant thin limestone of zone 3 caps these cuestas and hogbacks.

Gilliland zone 1 is correlatable with the Green River formation exposed inthe area of this report at least on the basis of lithology. For a precise correlation and establishment of correct relationships detail paleontologic work is required. The formation is rich both in faunal and floral remnants of past life. Bradley (1931, p. 1-56), has described microfossils of the oil shale of the Green River formation. The fossils, particularly the microfossils are well preserved and provide great opportunities for precise and detailed works.

Gilliland (1951, p. 39) reported a total thickness of 1150 feet of the Green River formation in Bald Knoll Canyon and 500 to 600 feet in the Valley Mountains.

In the area of this report, erosion has apparently removed the upper portion of the Green River formation and therefore no figures about the total thickness of the Green River are reported. However, a section of the Green River formation measured near the head of the south fork of Axehandle Canyon yielded a thickness of 520 feet.

Section of the Green River formation measured near the head of the south fork of Axehandle Canyon.

	Feet	Inches
Limestone, gray, dense, non crystalline to lithographic	1	6
Shale, red, arenaceous	10	3
Limestone, light-gray to grayish white, non-crystalline to lithographic		8
Shale, grayish green, arenaceous	2	2
Limestone, dense, hard, finely crystalline	1	6
Shale, gray, blocky	6	3
Shale, gray, hard, silty at base	11	6
Limestone, grayish white, lithographic	1	6
Siltstone, grayish brown, poorly cemented	13	2
Limestone, gray to grayish blue, massive	5	5
Silt, mottled	10	6
Limestone, gray to buff, fossiliferous near base massive, dense	90	2
Limestone, gray, finely crystalline to lithographic.	10	6
Shale, mottled	20	8
Limestone, gray, hard, non-crystalline	5	3
Shale, gray, blocky	5	3

Limestone, white to gray, chalky, fossiliferous

	Feet	Inches
fish scales (cycloid and ctenoid), fragments of bone (fish?)	48	6
Shale, gray, mottled, hard	35	6
Felsite porphyry, light tan ground mass abundant biotite phenocrysts	40	6
Shale, gray, soft, and friable	19	
Limestone, tan, finely crystalline to non-crystalline, massive	6	6
Shales, dark gray to black, blocky, calcareous near top	32	6
Limestone, buff to tan, non-crystalline to finely crystalline	2	6
Shale, grayish-brown, varved, hard, abundant plant fossils	8	3
Limestone, buff, tan and gray, dendrite stains, thin bedded, weather to white	16	6
Shale, brown, soft	28	3
Limestone white, hard, dense, oolitic in near top (otoliths? abundant)	38	6
Limestone, gray, non-crystalline to finely crystalline, sandy near base	4	6
Limestone and shale thinly interbedded, partially covered by debris	42	10
Total thickness	520	1

Relation to Adjacent formation

The Green River formation conformably overlies the Colton formation. However, there is evidence that "the lower strata of the Green River formation pass transitionally into the red beds of the Colton formation" (Gilliland, 1951, p. 39).

In the area of this report, the Green River is the youngest formation and thus is not overlain by another formation. As it occurs at the highest points of the area, it is not found in contact with the Quaternary deposits. Elsewhere, to the east and south of the Gunnison Plateau, a post-Green River formation, the Crazy Hallow overlies the Green River formation, however, it was not recognized in the area of this report.

Age and Correlation

The Green River formation has yielded numerous plant and animal fossils. In the area of investigation, the Green River formation yielded fish scales (both cycloid and ctenoid) and various bone fragments. The fish scales occur abundantly in thinly bedded limestone, which occur near the top of the formation.

On the basis of numerous plant and animal fossils found elsewhere in the Green River formation, it has been proved beyond doubt that the Green River represents deposition during Eocene times, more precisely during middle Eocene time. The intertonguing of the Green River formation with the Colton and Flagstaff formations poses some problem in ascertaining the exact age of all parts of the formation and it is very likely that the Green River formation has a regionally differing age. Wood (et.al., 1941, plate 1) has suggested that the age of the Green River formation ranges from late Wasatchian to Bridgerian. See table 2 (in pocket).

STRUCTURE

GENERAL FEATURES

It was pointed out earlier that the Gunnison Plateau lies in the transitional zone between the Basin and Range Province and the Colorado Plateau province. Hence the Gunnison Plateau contains structural characteristics of both the Great Basin and the Colorado Plateau provinces.

The over-all structure of the Gunnison Plateau is a braod syncline whose eastern limb is overturned. Schoff (1937, p. 140), and Speiker (1949, p. 77) both carried out investigations in the Gunnison Plateau area and have confirmed the synclinal structure of the Gunnison Plateau. A drive through Wales-Levan road provides an unique opportunity to observe the synclinal structure. In the words of Speiker (1949, p. 77) the main body of the Gunnison Plateau "is a solid syncline in the massive Indianola conglomerates, flanked to east and west by more intricate structre". A comparison of the eastern front with the western front of the plateau will reveal that the eastern front is structurally more complex and shows a high degree of deformation.

The discussion of the structure of the entire plateau is out of place and beyond the scope of this report. However, the structure of the area where the writer carried out investigations is treated here in detail, although the area itself constitutes a small portion of the plateau.

For the sake of convenience it is thought suitable to discuss the structure of the area under two sub-headings. The extreme structural complexity of the front and the area immediate to it on one hand and the extreme structural simplicity of the interior of the area on the other hand demands a separate discussion of each.

A. The intensely folded and faulted eastern plateau front and areas immediately adjacent to it.

B. The interior of the plateau, characterized by low dipping to almost flat-lying strata which have been only subjected to high angle normal faulting and broad open synclineal folding.

A. The plateau front and areas immediately adjacent to it.

a. Attitude of the strata.

The front of the plateau represents a belt of intensely disturbed strata. The beds exposed along the front and adjacent to it dip toward the main body of the plateau i.e., to the west. These beds rise gradually from the interior of the plateau and terminate abruptly at its eastern limit.

The entire front shows a greater variation in structure from Canyon to Canyon. In some canyons no structural complexities are observed. While in some, like Dry Canyon, greater structural features are discernable.

North of Coal Canyon the North Horn and Flagstaff strata are seen to rise gently from the interior of the plateau. These strata continue to rise attaining higher dips and finally terminating into a "bulky" promontory known as "the Point of the Mountain"

(Speiker, 1949, p. 29). In Coal Canyon itself, the strata which rise gently from the interior of the plateau almost assume a vertical attitude. These strata of the North Horn formation are seen to overlie the Idianola conglomerate. The relationship is that of angular discordance. However, it is difficult to ascertain whether the contact is simply an unconformable one or the proximity of the two formations is the result of the faulting. The Indianola conglomerates dip 45 degrees toward the northeast. It is noteworthy that elsewhere in the area, the North Horn formation either overlies the Twist Gulch formation or the Price River formation. This indicates that the contact between the North Horn and the Indianola is probably unconformable and not due to faulting (fig. 4, 5, and pl. 2) sec AA', BB' and CC').

Between Coal Canyon and Axehandle Canyon, an angular unconformity is present separating the overlying North Horn formation from the underlying Twist Gulch formation. In these two Canyons, most of the Twist Gulch formation is covered by debris from the overlying formations, nevertheless its outcrops continue along the northern boundary of the eastern extension of the front, between Axehandle Canyon to north and Rock Creek to south (pl 1). Farther south-east of Axehandle Canyon it passes under alluvium and is also downfaulted (fig. 5 and pl. 2 sec. BB').

At the eastern most extremity of the extension of the plateau front between Axehandle Canyon to north and Rock Creek to south, the North Horn formation and Indianola formations are exposed. Here the relationship appears to be the same as that observed north of Coal Canyon.

The strata exposed in between Dry Canyon and the southern end of the thesis area show the same attitude as observed in Axehandle and Coal Canyons. Immediately south of Dry Canyon a massive steep cliff of the Price River formation lying between the Twist Gulch and the North Horn formation rises gently from the interior of the plateau and terminates at the end of the plateau front with an abrupt change in dip. Here the Price River strata assumes a vertical attitude.

The Twist Gulch formation is exposed along the base of the plateau front between Dry Canyon and the southern end of the thesis area. Here it shows greater thickness and dips strongly toward the east (pl. 1).

b. Faults.

The most striking structural features of the area of investigation are many faults which traverse the area both from east to west and north to south. However, the east-west striking faults are more prominent than the north-south striking faults.

Two distinct sets of faults are present in the thesis area. The major or principal set trends approximately N 85 W and across the plateau. The other minor set trends N 15 E approximately parallel to the plateau front.

North of Axehandle Canyon no major structural features are present. However, south of Axehandle Canyon, the entire plateau front shows structural complexities.

Immediately south of Axehandle Canyon the plateau front extends toward east into the Sanpete Valley. This eastward extension of the plateau front in between Axehandle Canyon and Rock Creek is the result of a series of high angle step faults (fig. 5 and pl. 2). These faults strike approximately N 15 E in an arcuate manner parallel to the axis of a minor feld, and dip away from the point toward Sanpete Valley. Similarly trending minor faults are present farther south of Dry Canyon (p. 1). However, because of their confinement in the Twist Gulch formation not much areal extent and vertical displacement is involved.

Gilliland (1951, p. 60-61), reported similarly trending set of faults from the Valley Mountains, Gunnison quadrangle. However, in the Valley Mountains the NE striking faults are the major structural features. Whereas in the area investigated, the N 15 E trending faults form a minor structural feature, unless the entire eastern front of the Gunnison Plateau is the outcome of faulting. In Speiker's opinion a ramp type thrust structure, which caused the Gunnison Plateau to assume its present day position above the Sanpete Valley, exists, but is hidden by alluvium (Hunt, 1948, p. 81).

Between eastern extension of the plateau front and the Rock Creek two high angle normal faults striking approximately east-west are easily recognized. These faults are the northern boundary faults of the "Dry Canyon graben". The faults dip toward the graben. These faults together with the other east-west striking faults constitute the other prominent set of faults striking approximately N 85 W. These faults have faulted the Flagstaff formation (limestone) down to the level of the Canyon floor. North of these faults, the Flagstaff formation (limestone occupies higher altitudes along the front.

South of Dry Canyon, two high angle normal faults striking approximately east-west mark the southern boundary of the graben (pl. land 2). Along these faults, the Flagstaff formation (limestone) is faulted down to the level of the canyon floor. The Flagstaff formation (limestone)is down faulted from elevations of 7,500 feet to 6,000 feet between the north and south boundary faults of the Dry Canyon graben. Flsewhere on either side of this graben and the entire front the Flagstaff formation (limestone) occupies higher points (Speiker, 1949, p. 74).

In the graben block (pl. 2 sec AA') there is no more than 100 feet of North Horn strata. The North Horn strata overlie the Twist Gulch formation and are in turn succeeded by the Flagstaff strata which forms the bulk of the strata exposed in graben. On either side of this graben, the North Horn strata are seen to attain a thickness of as much as 1000 feet (Speiker, 1949, p. 74). According to Speiker (1949, p. 74), the faulting which gave rise to Dry Canyon graben is "the earliest known normal faulting in the region". It is assumed that the faults "must have been active in North Horn and perhaps Price River times". It is believed by Speiker (1949, p. 74) that a reversal of movements on faults transformed a horst to give rise to present day "Dry Canyon graben". Undoubtedly Speikers thesis explains the difference between the thickness of the North Horn strata exposed in the graben and those exposed on either side of the graben, however, evokes some difficult questions which are hard to explain in terms of tectonics.

Farther south, about one mile north of Maple Canyon (pl 1 and 2, sec. AA') another fault is present, which strikes in an east-west direction and dip toward the north at an angle of about 75 degrees. This fault, the last of a series of three step faults to the south of Dry Canyon and the "Dry Canyon graben" is the last major structural feature in the south of the area. If Speikers (1949, p. 74) thesis is correct about the faults which gave rise to "Dry Canyon graben", then this fault which is present about one mile north of Maple Canyon is younger than any other fault which gave rise to the "Dry Canyon graben". Most probably all the faults present in the area except those which gave rise to the "Dry Canyon graben" can be dated post-dating the deposition of the Green River formation.

Origin of Dry Canyon graben.

The "Dry Canyon graben" is the most prominent structural feature present in the area. It presents an interesting tectonic problem. As mentioned before Speiker (1949, p. 74) thinks that the present day "Dry Canyon graben" was a horst and the faults were active in Price River-North Horn times.

The faults which bound the graben block dip steeply and are not quite vertical. If Speiker's (1949, p. 74) thesis is correct, then the faults defining the "Dry Canyon graben" were initially reverse. The subsequent reversal of the movement caused an initial horst to change into the present day graben.

This thesis undoubtedly explains the meager thickness (100 ft.) of the North Horn strata present in the graben block. However serious tectonic problems are evoked when the stress forces required to give rise to reverse faults are considered. No north south-acting stress forces are known to have operated in the area during North Horn - Price River time.

It is possible that Speiker's "horst" (1949, p. 74) was caused by the plastic intrusion of the halite from the Arapien shale and the Twist Gulch formation into the overlying strata. The plastic intrusion of salt does not need any tectonic forces. "The motive force is the difference in density between the salt and the surrounding sediments" (Billings, 1962, p. 259).

This plastic intrusion of the salt must have pushed the effected block out of the basin of deposition. This explains the small thickness (100 ft.) of the North Horn strata present in the graben block.

The subsequent dissolution of salt intrusion caused the collapse of the "horst" block, thus giving rise to present day "Dry Canyon graben".

c. Torreva Blocks of Flagstaff Formation (limestone).

Between Axehandle and Dry Canyons a number of low lying hills are observed. These hills vary in height and their areal extension. The largest of these is seen between Rock Creek and Dry Canyon.

These hills are dominantly huge chunks of the Flagstaff Formation (limestone). From their location and orientation it is apparent that these hills represent huge block detached from the plateau front. No slickenside markings were observed on these blocks. Therefore it is apparent that these blocks represent Reiche's Torreva blocks (1931, p. 533).

d. Recent faulting.

Farther east of the front and in the Sanpete Valley, a series of scarplets striking in northeast-southwest direction are present (pl. 1). The faults are confined to alluvium and give rise to several scarplets, and dip in a south-east direction toward the Sanpete Valley.

These scarplets represent the recent Basin and Range faulting, so characteristic of the Basin and Range province.

B. The Interior of the plateau.

A detailed survey of the interior regions of the area of investigation revealed no structural complexities as observed at the front. The only prevalent structural features are the high angle east-west striking normal dip slip faults. Otherwise the beds are seen to be nearly horizontal or very gently dipping being a part of the central synclinal structure.

GEOLOGIC HISTORY

The stratigraphic sequence (Table 1), in the area of investigation (figs. 1 and 2) which lie on the eastern slope of the Gunnison Plateau between Coal Canyon to the north and Maple Canyon to the south, reveals a series of geologic events which occurred from upper Jurassic to post-Eocene time. Some of these episodes are directly inferred whereas some are inferred indirectly from the lithology of the formations exposed in the area or from general regional relationship.

The oldest formation exposed in the area is the Twist Gulch formation. The Twist Gulch formation represents deposition during Upper Jurassic time and is the only marine deposit exposed in the area. From the study of the regional distribution of the Twist Gulch formation, it is evident that the formation was deposited in a basin which occassionally lacked drainage and was temporarily closed. Occurrence of gypsum and salt indicates the prevalence of such environments.

The Morrison formation which overlies the Summerville of the San Rafael group of eastern Utah and Colorado is conspicuously absent from the area of investigation, and so are the Lower Cretaceous deposits.

The next youngest formation exposed in the area of investigation is the Indianola group. The Indianola group is not observed in contact with Twist Gulch formation at any locality in the area investigated. Speiker (1946, p. 158) suggested that after the deposition of the Twist Gulch formation a period of geologic neutrality or non-deposition followed which persisted till the beginning of the

Indianola time. This non-deposition period was followed by an orogenic episode occurring "not too great a distance to the west" (Hunt, 1948, p. 79). As a result of this orogeny the Indianola formation, a coarse and heterogeneous clastic sedimentary unit was deposited. Speiker (1946, p. 149-152 and 1949, p. 79-81) referred to this orogenic movement to the "mid-Cretaceous" or "early Colorado".

Speiker (1949, p. 78) asserts that "the conglomerates in the lower part of the Indianola group are of Molasse type, like the Price River, and they can hardly mean anything other than orogeny not far to the west".

The deposition of the Indianola conglomerates continued through Colorado time, however, in the opinion of Speiker (1949, p. 79) the upper part of the Indianola is different from the lower part in lithologic characters. He attributes these lithologic differences to the renewal of orogeny in the west. According to Speiker (1949, p. 79) this renewal of early Colorado orogeny occurred during late Colorado(?) time.

The late Colorado(?) orogeny was followed by a period of non-deposition. This interval was followed by another orogenic movement in middle to late Montana time. This orogenic movement is designated as early Laramide by Speiker (1946, p. 152-155). Early Laramide orogeny was much stronger and intense than any others which have occurred previously. The early Laramide orogeny caused folding and was followed by a period of mass-wastage and erosion. This erosion removed most of the original Indianola from the area studied. Only a few isolated and scattered pockets remained on the fresh erosional surface now underlain mainly by the Twist Gulch formation. This explains the present day patchy distribution of the Indianola deposits in the area investigated.

After the early Laramide orogeny had ceased, another period of non-deposition ensued, which persisted through the most of Price River time. Only during upper middle Price River time did the area start receiving clastic sediments once again. However, these sediments which were being supplied from the west, were deposited in channels and in the low lying areas. The discontinuous and patchy occurrence of the Price River formation is a clear-cut evidence of its' channel origin particularly in the area of investigation.

It is evident that near the close of Price River time another orogenic disturbance, it is believed, was responsible for the supply of clastic sediments which constitute the Price River formation. It is believed that his orogeny was a renewal of the early Laramide orogeny, or that the orogeny persisted spasmodically if not continuously.

The coarse clastic sedimentary rocks, so characteristic of the North Horn formation exposed in the area are strong evidence for the continuity of the orogeny even in to lower and middle North Horn time.

During upper North Horn time a period of stability was attained and the dominant fluviatile conditions gave way to mixed fluvio-lacustrine environments, which ultimately passed into lacustrine environments of Flagstaff time. The lacustrine environments persisted from upper North Horn time through Green River time. The non-clastic nature of the upper North Horn formation, the Flagstaff formation (limestone), the Colton formation, and the Green River formation is unequivocal evidence for lacustrine environments. In general, with the beginning of upper North Horn time, the orogenic movements have ceased and the highlands to the west (which have been source area for the clastics since Indianola time) were leveled down and a relatively orogenically quiet geologic interval ensued. This interval as stated above continued almost without major interruptions through Green River time. However, it was punctuated by volcanic activity. The occurrence of glass shards in the Flagstaff formation (limestone) and felsitic lava (tuff?) flows in the Green River formation are indicative of volcanic activity in the area. The volcanic activity during Flagstaff time was explosive whereas during Green River primarily lava flows developed without major violent volcanic activity.

Volcanic activity is reported from other parts of the Gunnison Plateau. Hunt (1949, p. 109-116) reported lava flows from the northern part of the Gunnison Plateau whereas Zeller (1949, p. 60-61) reported lava flows interbedded with the Green River formation from the mid-western part of the Gunnison Plateau.

It is most probable that the mineralization of the lower part of the North Horn formation exposed in the area of investigation is related to igneous activity of Green River time. Hunt (1949, p. 109-116), and Zeller (1949, p. 60-61) both reported the occurrence of quartz monzonite intrusive bodies from their areas of investigation. It is believed that the lava flows and quartz monzonite intrusions are contemporaneous and had a common origin.

The remaining notable geologic events which followed the deposition of the Green River formation in the area of investigation was primarily vertical uplift (Basin and Range Epeirogeny), detected in the period or periods of deformation. This deformation brought the present day Gunnison Plateau into existence.

In the first phase of post-Green River deformation the beds were subjected to the initial north-south folding. The folding was accompanied by a minor amount of thrusting (Hunt, 1948, p. 80 and Speiker, 1949, p. 72-77). These structures were later broken by north-south and east-west striking normal high-angle faults. It is difficult to determine whether these structures preceeded "or were contemporaneous with the formation of a larger ramp type strucutre parallel to the "eastern front" (Hunt, 1948, p. 81). According to Speiker this ramp structure exists, but is hidden by alluvium. In Speikers opinion it is the ramp type thrust structure which caused the Gunnison Plateau to assume its present-day position above the Valley (Hunt, 1948, p. 81).

This phase of orogenic movements can be dated as post-Green River time. The local evidence supports the above dating. However Speiker (1949, p. 74), thinks that the normal, high angle faults, which bound the Dry Canyon graben are older than the other faults in the area, and were active in North Horn or perhaps even in Price River time. If it is true, it records the earliest known normal faulting in the region (Speiker, 1949, p. 74-75). Unfortunately it is not possible to determine the accuracy of Speiker's (1949, p. 74-75) thesis. However, strip thrusting and folding is known to have occurred in post-Eocene time south of the Gunnison Plateau (Speiker, 1949, p. 78).

Eardley (1933, p. 394-397), who carried out investigation in the Southern Wasatch Mountains, concluded that movement began in late Tertiary, "post-dating the deposition of the Salt Lake formation in Pliocene time" (Eardley, 1933, p. 397). The scarplets which strike northeast-southwest and can be traced over a long distance along the western side of the Sanpete Valley lend support to the continuence of movement in present time.

The table on the next page presents a summary of the main geologic events which occurred in the Gunnison Plateau in general and area of investigation in particular.

Table 3

	GEOLOGIC EVENTS	AGE
1.	Deposition under marine environments (Twist Gulch Formation - shales and siltstone)	Upper San Rafael Group
2.	Uplift, Orogenic (?) followed by a period of non-deposition and non-erosion?	Late Jurassic & ? Lower Cretaceous
3.	First orogenic uplift not far to the west followed by erosion	Early Colorado
4.	Deposition mainly under fluviatile environments (Indiancla, coarse clastics, heterogeneous and variegated sediments)	Colorado
5.	Orogeny, the Early Laramide accompanied by folding in the area investigated.	Medial Late Montana
6.	A period of extensive erosion causing the removal of most of the Indianola Group in the area.	Middle Montana to Late Fox Hills
7.	Renewed orogeny not far to the west followed by the deposition of the Price River Formation and Lower North Horn.	Lance
8.	Normal faulting (Late North Horn).	Paleocene
9.	Establishment of lacustrine environments which persisted through the deposition of the upper North Horn, Flagstaff, Colton, and Green River Formations	Fort Union Wasatch, and Green River
10.	Igneous activity (intrusive and extrusive) emplacement of intrusive bodies in northern and mid western part of the Gunnison Plateau, deposition of lava flows both in the area investigated and other parts of the Gunnison Plateau. Mineralization of the lower part of the North Horn Formation in the Dry Canyon region of the area investigated.	Green River
11.	Basin and Range faulting bringing the present day Gunnison Plateau into existence.	Post-Eocene (Pliocene?) to Present
12.	Renewal of Basin and Range faulting. Faulting of alluvium of Sanpete Valley giving rise to prominent scarplets.	Recent

A Summary of the Geologic History of Dry Canyon and Vicinity, Gunnison Plateau, Sanpete County, Utah.

ECONOMIC GEOLOGY

The area of this report has been prospected in the past, the evidence of which consists is furnished by several prospects opened at various levels in the North Horn formation throughout the eastern front of the Gunnison Plateau.

In the northern parts of the Gunnison Plateau coal has been mined from the North Horn strata exposed in the vicinity of Wales. Richardson (1906), published a series of articles about the coal-fields in the vicinity of Wales. The southern parts of the plateau particularly south to Wales were also prospected for coal. An abandoned coal mine in Coal Canyon and a shaft located northward in Axehandle Canyon indicate coal prospecting duirng the past in this part of the plateau. Both the coal mine and shaft are located in the North Horn formation.

Farther east toward Sanpete Valley, the area has been investigated and tested for underground water (Richardson, 1906).

SULFIDE DEPOSITS

South of Axehandle Canyon the region has been examined and prospected for metallic deposits. Galena, pyrite, and chalcopyrite are known to occur in the western and northwestern parts of the Gunnison Plateau (Hunt, 1949, p. 109-116 and Zeller, 1949, p. 74). In these localities, the mineralization is associated with quartz-monzonite porphyry. In the vicinity of Dry Canyon, however, no such association is present. No igneous intrusive rock is evident in the area either in the North Horn formation or in formations adjacent to it.

As stated previously, the metallic sulfides in the vicinity of the Dry Canyon region and the entire area have been prospected by local miners and prospectors, however, no economic deposits have been discovered. Recently, once again a local prospectors and miner from Ephraim has revived mineral explorations in this part of the plateau.

Based on recent investigations, which the writer carried out during the last summer of 1966, it is believed that the area has no immediate economic importance, although an extensive drilling operation may yield some substantial information in regard to the exact extent and economic feasibility of the sulfide deposits.

GEOLOGIC FORMATIONS

In the stratigraphic part of this thesis, the lithology of the North Horn formation is described in detail (See pages 46-58). However, the occurrence of sulfides in the North Horn strata present between Axehandle and Dry Canyons requires a detailed study.

The North Horn formation exposed north to Dry Canyon and in the upper parts of the eastern extension of the plateau front (pl. 1), is extremely heterogeneous and shows remarkable textural and lithological variations.

Lithology

The mineralized strata of the North Horn formation are composed of three distinct lithologic units. Intergradation of one unit into the other is an ubiquitous phenomenon displayed by the upper Mesozoic-Cenozoic formations of the Gunnison Plateau. Consequently the North Horn formation shows large scale lithologic intergradations. The three dominant lithologic units from bottom to top are:

3. Limestone, dolomitized and silicified
2. Sandstone, calcareous and graywacke type
1. Conglomerate

The above sequence is repeated at various stratigraphic intervals throughout the entire thickness of the North Horn formation present in this locality. The repetition of the above mentioned sequence suggests a cyclical sedimentation in the North Horn basin reflecting the oscillatory tectonic environments in the source area of the North Horn sediments.

As the three units (conglomerate, sandstone, and limestone) play an important role in the localization and lithological control of sulfide deposits, it is worthwhile to discuss each of the three lithologic units in detail.

Conglomerate

The conglomerate is mainly composed of quartzite and limestone pebbles varying in size from $\frac{1}{2}$ inch to 1 $\frac{1}{2}$ inch in diameter. The pebbles, sub-rounded to rounded, are embedded in a coarse to medium grained sandy matrix.

The pebbles in the conglomerate are oriented along the bedding plane and show elongation parallel to the bedding plane. The limestone pebbles show this feature more prominently than quartzite pebbles, primarily because of the difference in composition and hardness.

The elongation is presumably the result of stress perpendicular to the bedding planes.

On the basis of regional relationships it is suggested that the source of the stress forces was subterranean. Possibly the emplacement of an intrusive igneous body provided the necessary directed pressure. Elsewhere (western and northwestern parts of the Gunnison Plateau and Mnt. Nebo) igenous intrusive bodies of quartz monzonite composition are present and are found to intrude the country rock concordantly as well as discordantly.

The effect of the directed pressure seems to diminish toward the upper parts of the North Horn strata. This evidently supports the proximity of an igneous intrusive body.

Sandstone

The conglomerate grades upward into coarse-grained sandstone of dark-gray and light-gray colors. The lower strata of the sandstone unit show prominent cross-bedding.

The sandstone can be classified as a sub-graywacke, as it is composed of rock fragments besides poorly sorted and angular grains of quartz, chalcedony, and feldspar. The rock fragments are mostly limestone, quartzite, and sandstone pebbles. Of all the rock fragments, the fragments of algal limestone are most abundant. The cement is mostly calcareous. Recrystallized calcite shows up prominently in thin sections of the sandstone. The calcareous cement and recrystallized calcite is replaced by cryptocrystalline silica, which in turn is replaced by galena.

The coarse-grained sandstone grades upward into fine-grained sandstone of light-gray color. The fine-grained sandstone is mostly composed of angular to sub-angular and sub-rounded quartz, feldspar, and chalcedony. Galena is conspicuously absent in fine-grained sandstone, however, pyrite is present. Its veins cross-cut each other.

Limestone

The fine-grained sandstone grades into calcaresous shale and finally into limestone. The limestone strata are silicified and dolomitized. Three types of limestones are distinguished in the mineralized area.

1. Non-crystalline to crystalline limestone
2. Oolitic limestone
3. Nodular and algal limestone

The limestone strata are fractured and broken, however, no localization of sulfide deposits has occurred in these fractures. The dolomitization of the limestone has led to the destruction of the original texture and the development of new textures. Perfect crystals of dolomite can be seen in thin sections (fig. 6).

Of all the varities of limestone, the nodular limestone is most abundant. The oolitic limestone is present in subordinate quantities, however, its oolitic texture is hardly discernable.

GALENA MINERALIZATION

Nature of galena mineralization

Galena occurs as disseminated in conglomerate, conglomeratic sandstone, and sandstone. In hand specimens galena occurs in the pore spaces between detritical grains. In thin sections it replaces calcite, chalcedony, and quartz (figs. 7-14). A detail petrographic study of many samples of sandstone revealed that galena does not occur as a clastic particle in the host rocks. It lacks all the important characteristics of exogenically transported clastic particles. Definite crystal outline and its selective occurrence in the midst of replaced cement rules out the possibility of galena being clastic or detrital.

PYRITE AND CHALCOPYRITE DEPOSITS

Nature of pyrite mineralization

Pyrite and chalcopyrite is present in limestone and sandstone strata of the North Horn formation. Crystals of pyrite and chalcopyrite are widely distributed in the upper strata of the North Horn formation. However no economic concentrations are present in either the limestone or sandstone nor conglomerates.

The pyrite in limestone strata shows definite features related to replacement phenomenon, e.g., replacement veinlets, selective

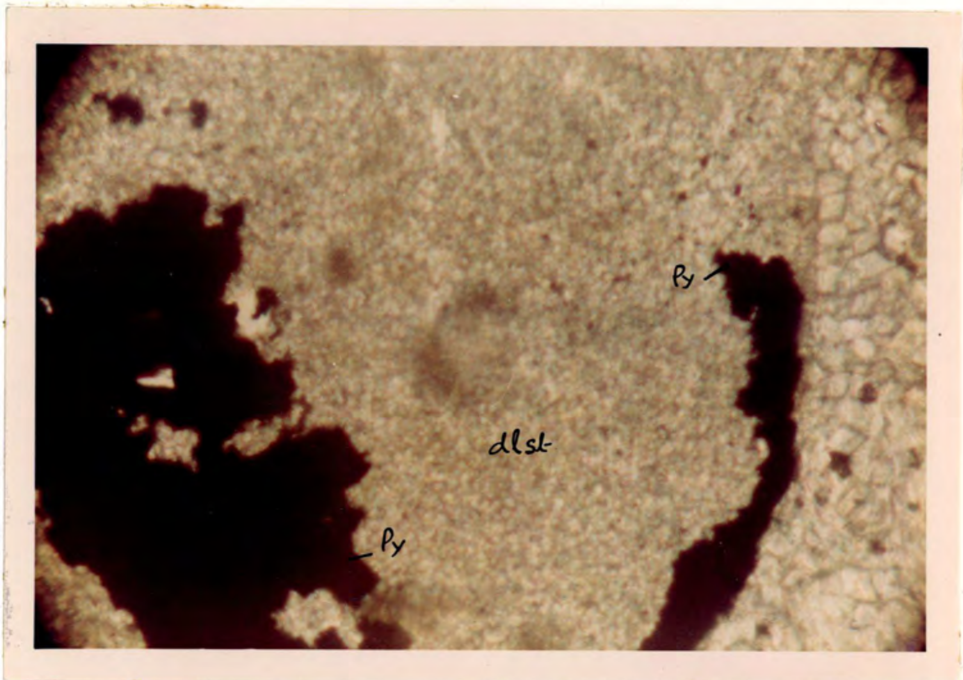

Figure 6. — Photomicrograph showing dolomitized limestone.

Perfect crystals of dolomite can be seen on the right of the picture.

Py = Pyrite dlst = dolomitized limestone

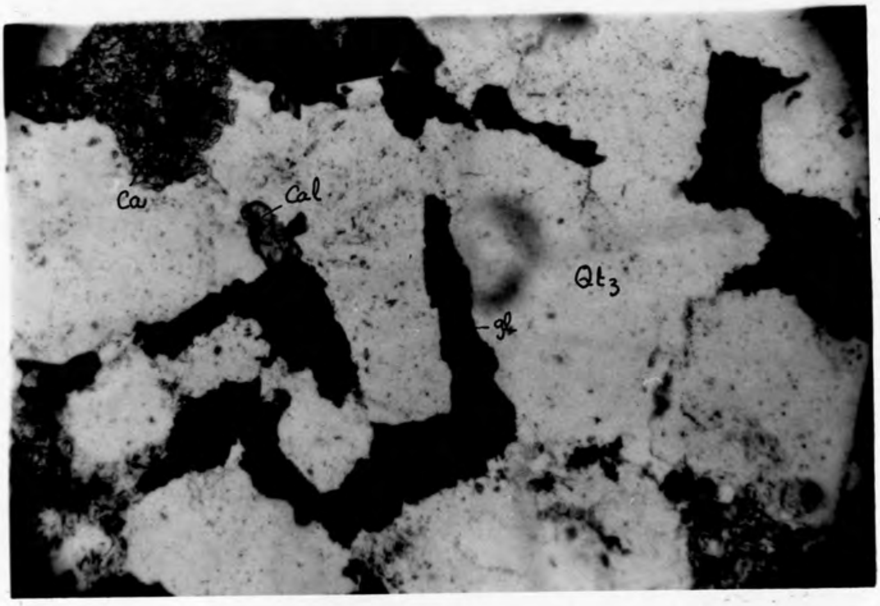

Figure 7.--Photomicrograph showing galena (black) replacing quartz, chalcedony and calcite.

gl = galena, cal = calcite
ca = chalcedony and qtz = quartz

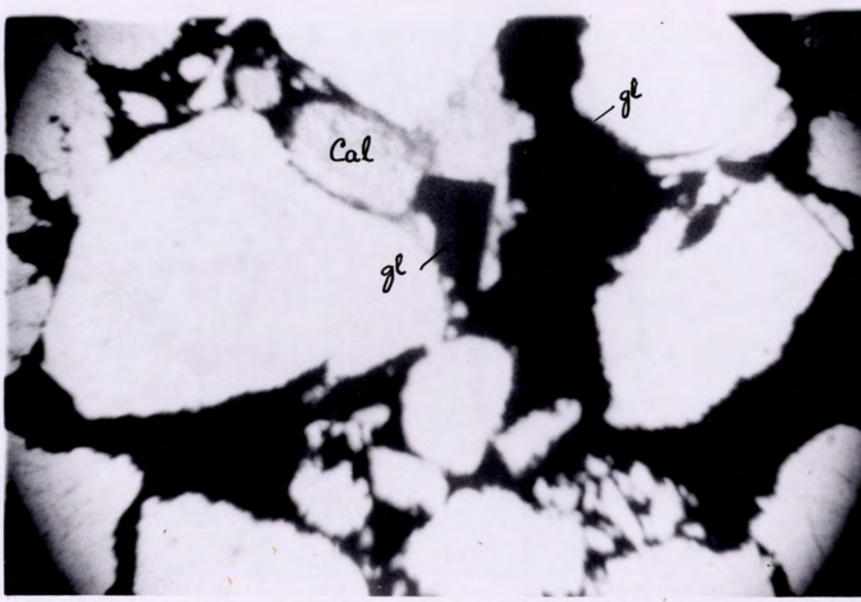

Figure 8.— Photomicrograph showing galena replacing calcite cement and assuming crystalline outline.

gl = galena   Cal = calcite

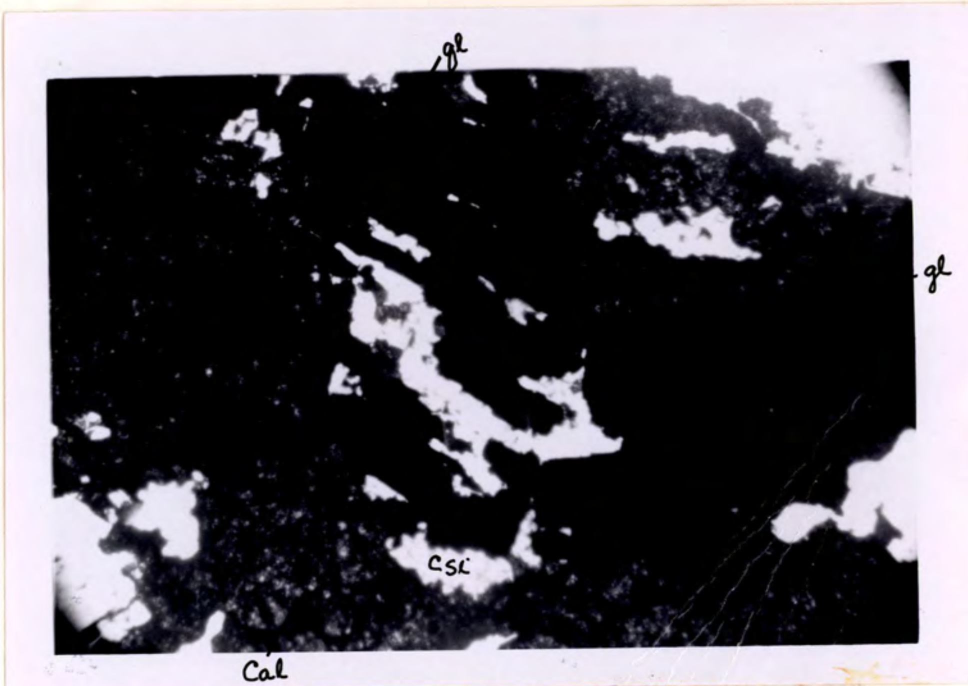

Figure 9.--Photomicrograph showing galena (black) replacing crypto-crystalline silica and calcite.

cal = calcite   gl = galena
C Si = Cryptocrystalline Silica

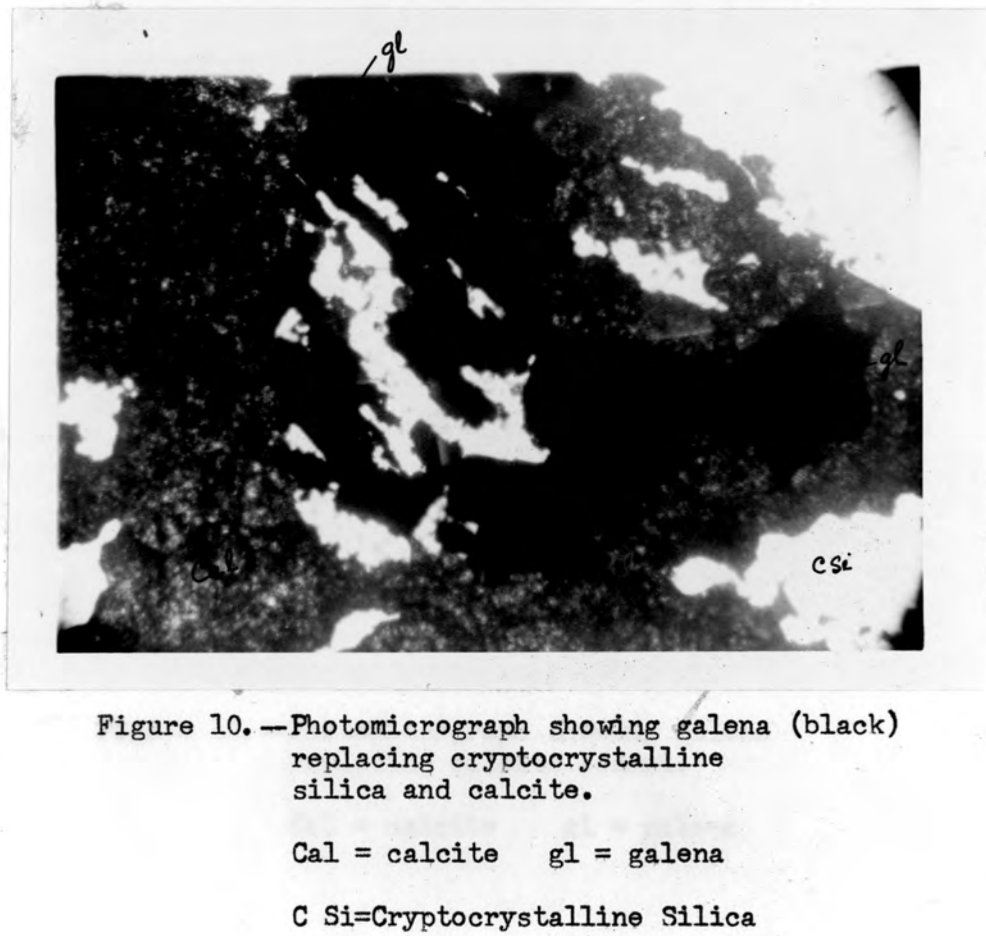

Figure 10.—Photomicrograph showing galena (black) replacing cryptocrystalline silica and calcite.

Cal = calcite   gl = galena

C Si=Cryptocrystalline Silica

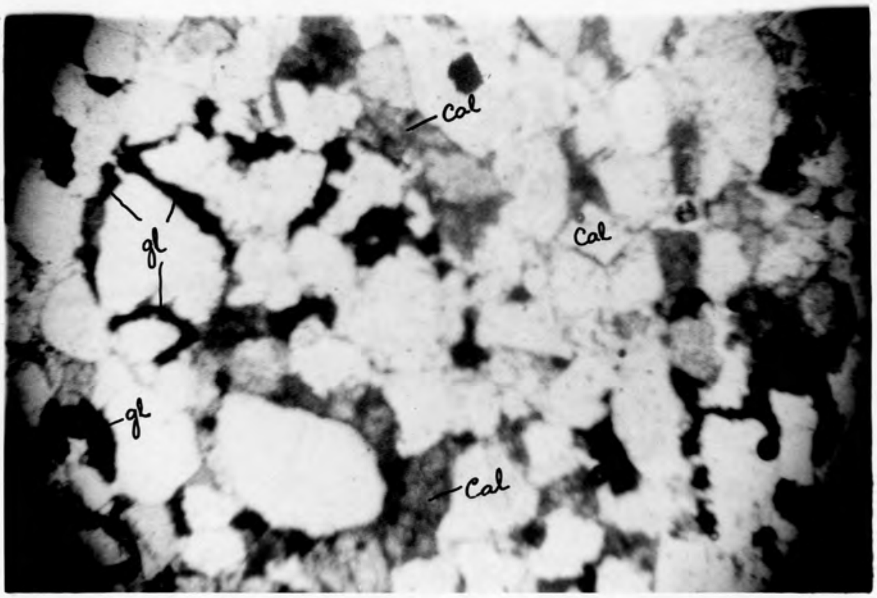

Figure 11.--Photomicrograph showing galena replacing calcite cement.

Cal = calcite gl = galena

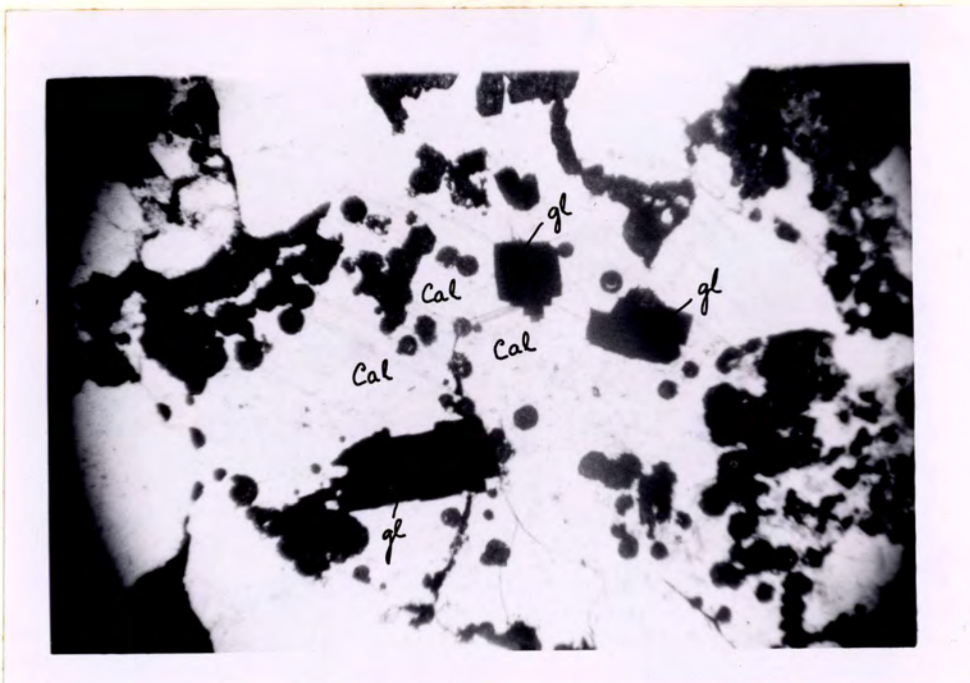

Figure 12.—Photomicrograph showing galena replacing calcite and assuming pseudo-rhombic outline.

Cal = calcite   gl = galena

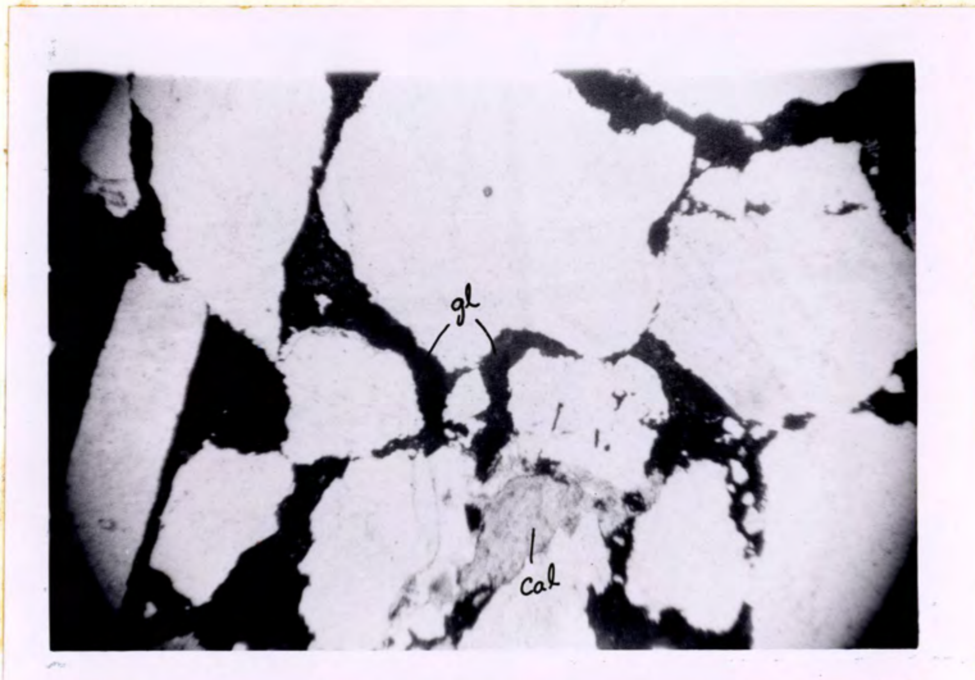

Figure 13.—Photomicrograph showing galena replacing calcite. Specks of galena can be seen in quartz grains.

Cal = calcite gl = galena

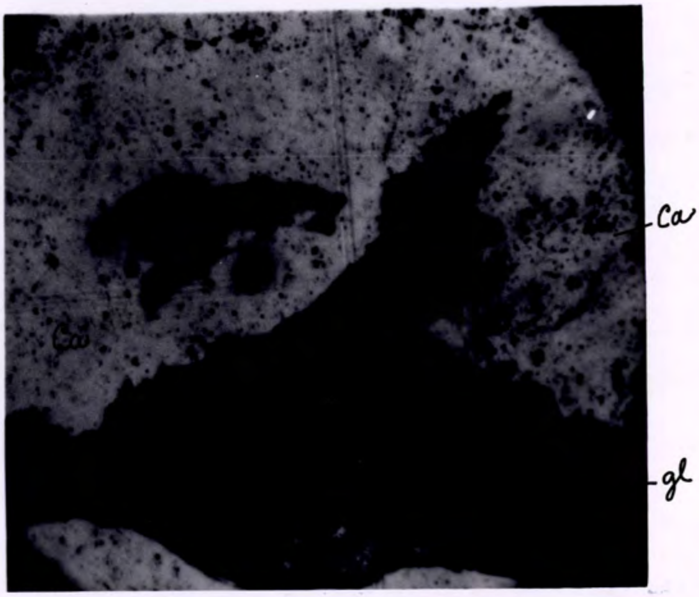

Figure 14.--Photomicrograph showing galena replacing chalcedony.

Ca = chalcedony gl = galena

replacement, localization along textural features of host rock, and islands of host in quest all of which are the typical replacement features present in the pyritized limestone (figs. 16-30).

The introduction of pyrite post dates dolomitization and silicification. Dolomitization and silicification resulted in the development of crystals of dolomite and quartz (figs. 6 and 19).

LITHOLOGIC CONTROLS-HOST ROCKS

The eastern extension of the plateau front between Axehandle Canyon and Rock Creek is the outcome of high angle normal dip slip faults, which strike about N 15°E in an arcuate manner (pl. 1).

It is noteworthy that the faults show no mineralization, although it may still be possible that the mineralizing fluids may have ascended through these faults. Similarly the major joint system of the area shows no sulfide deposition. Nevertheless some of the joints are lined by dog tooth spar, a variety of calcite.

From the above discussion it is apparent that the lithology of the mineralized rock units and their porosity and permeability have exerted some control on the localization and deposition of galena, pyrite, and chalcopyrite deposits.

PARAGENESIS

A definite paragenetic sequence of sulfide development is difficult to establish. However, from the study of numerous thin sections and few polished surfaces a rough approximation about the sequential formation of sulfides was obtained.

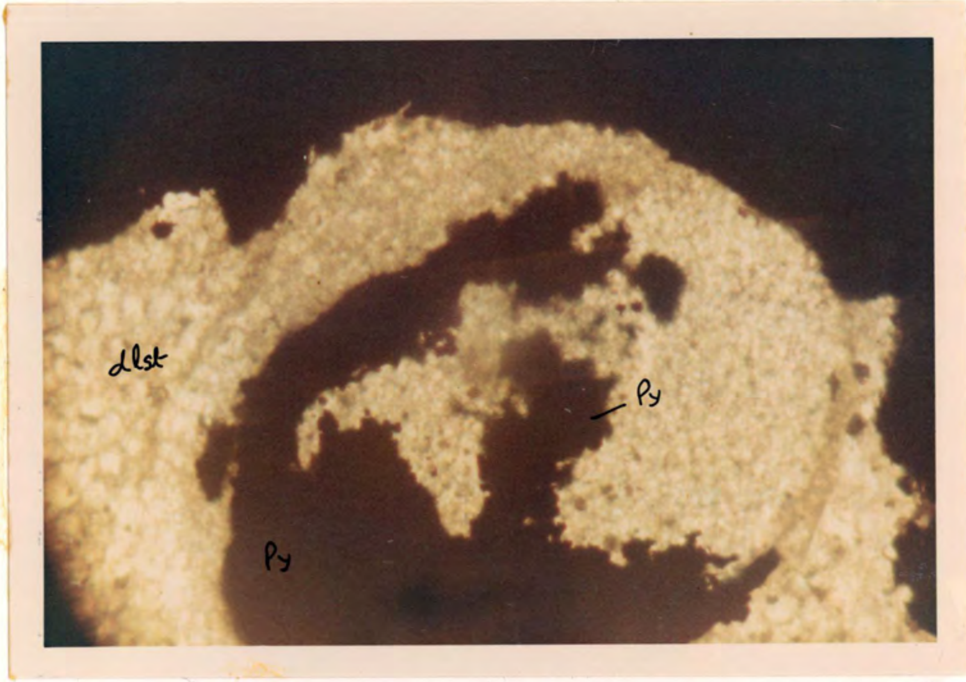

Figure 15.--Photomicrograph showing selected replacement of dolomitized limestone by pyrite.

Py = pyrite   dlst = dolomitized limestone

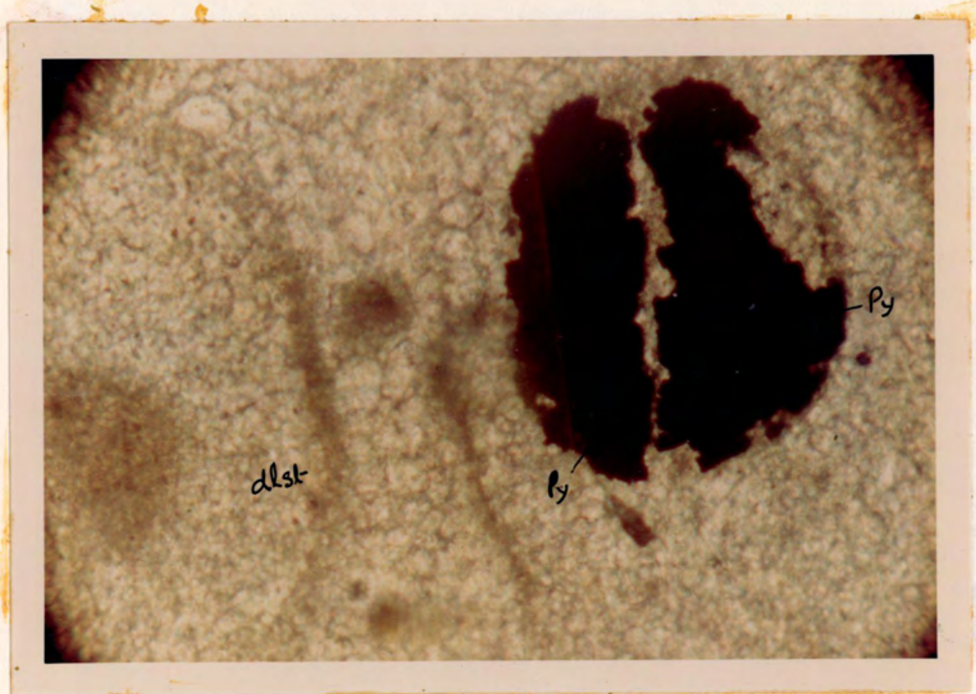

Figure 16. — Photomicrograph showing pyrite replacing oolite.

Py = pyrite dlst = dolomitized limestone

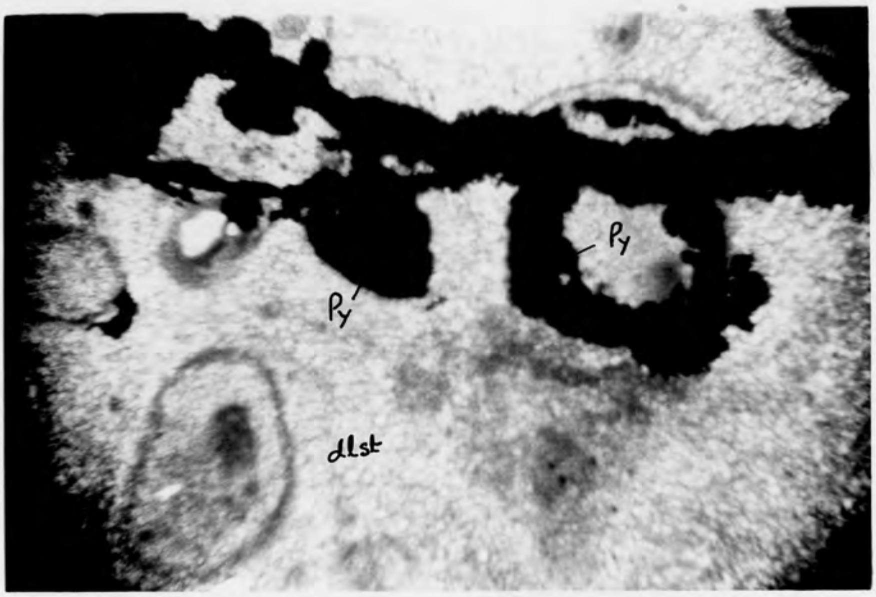

Figure 17.—Photomicrograph showing matching walls and complete and partial replacement of oolites by pyrite

Py = pyrite dlst = dolomitized limestone

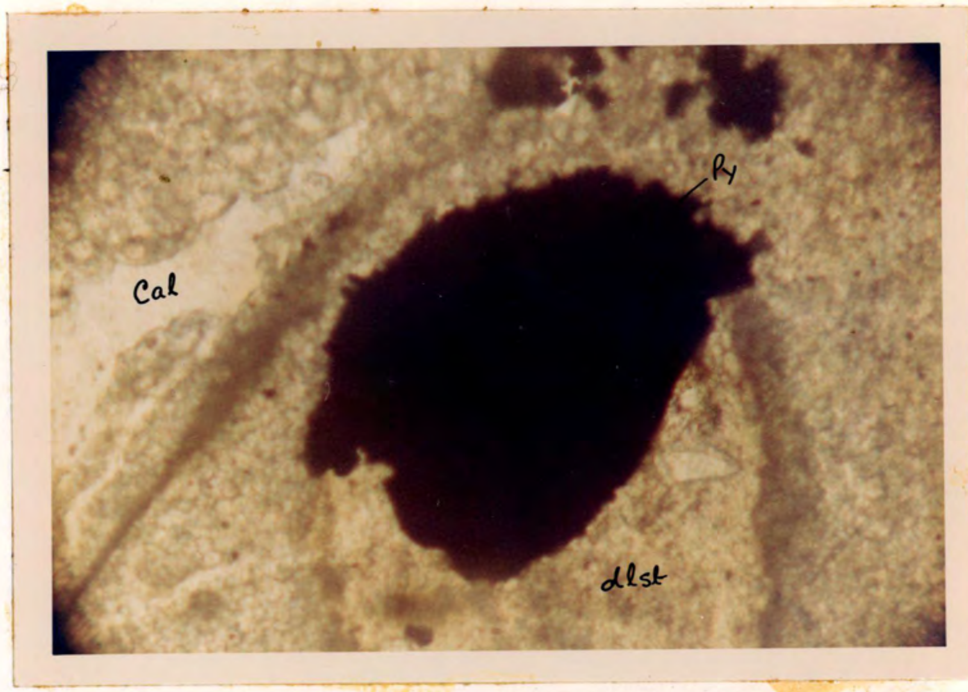

Figure 18.--Photomicrograph showing a partially replaced oolite. A calcite vein can be seen on left.

Cal = calcite Py = pyrite
dlst = dolomitized limestone

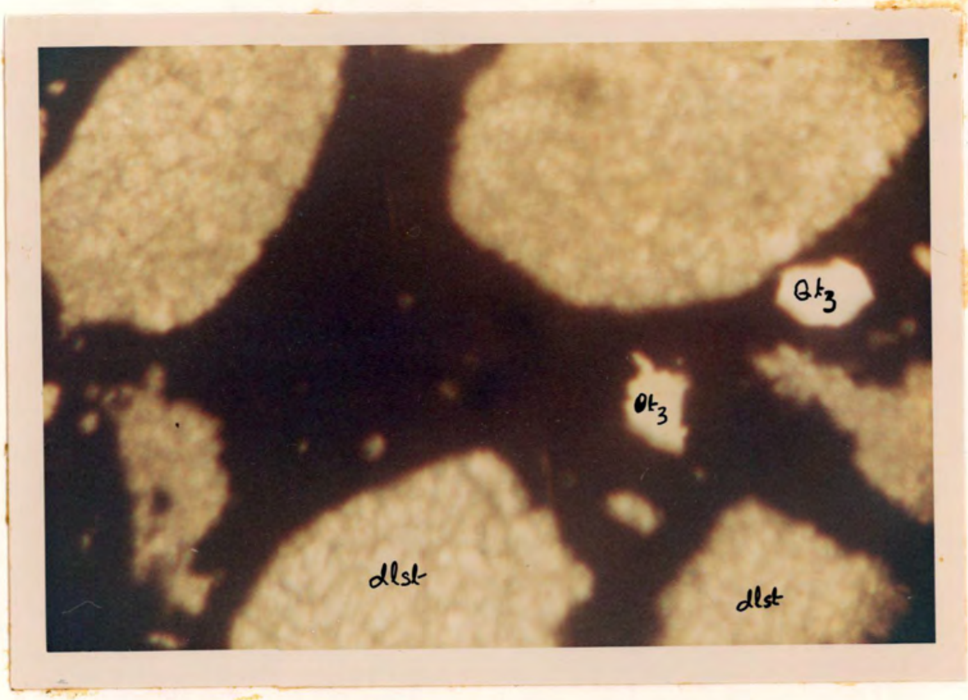

Figure 19. — Photomicrograph showing quartz replacing pyrite.

Py = pyrite, Qtz = quartz
dlst = dolomitized limestone

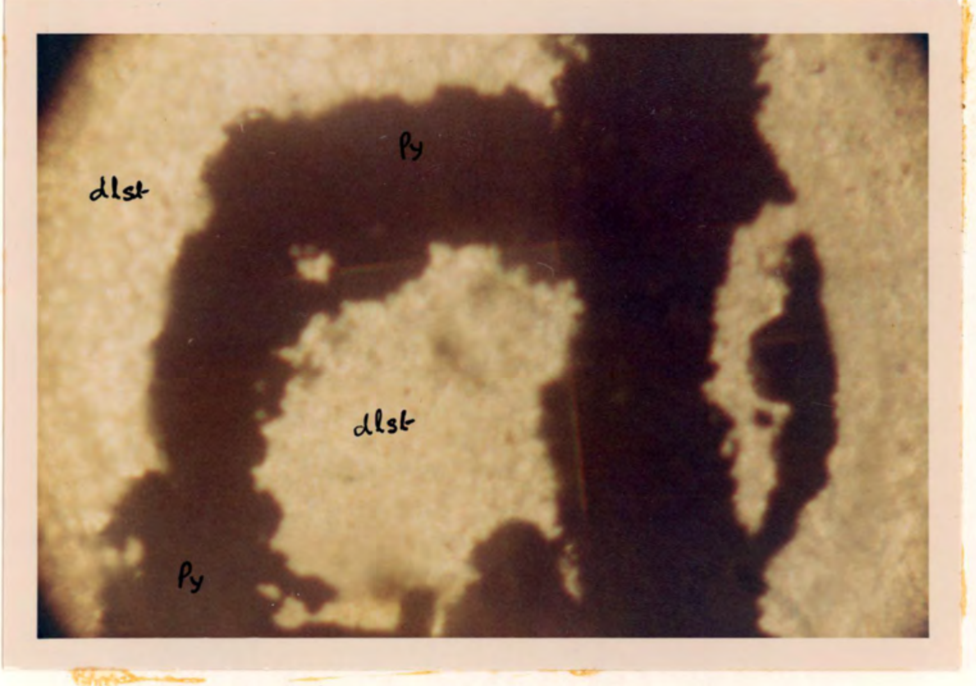

Figure 20. — Photomicrograph showing island of host rock in pyrite.

Py = pyrite dlst = dolomitized limestone

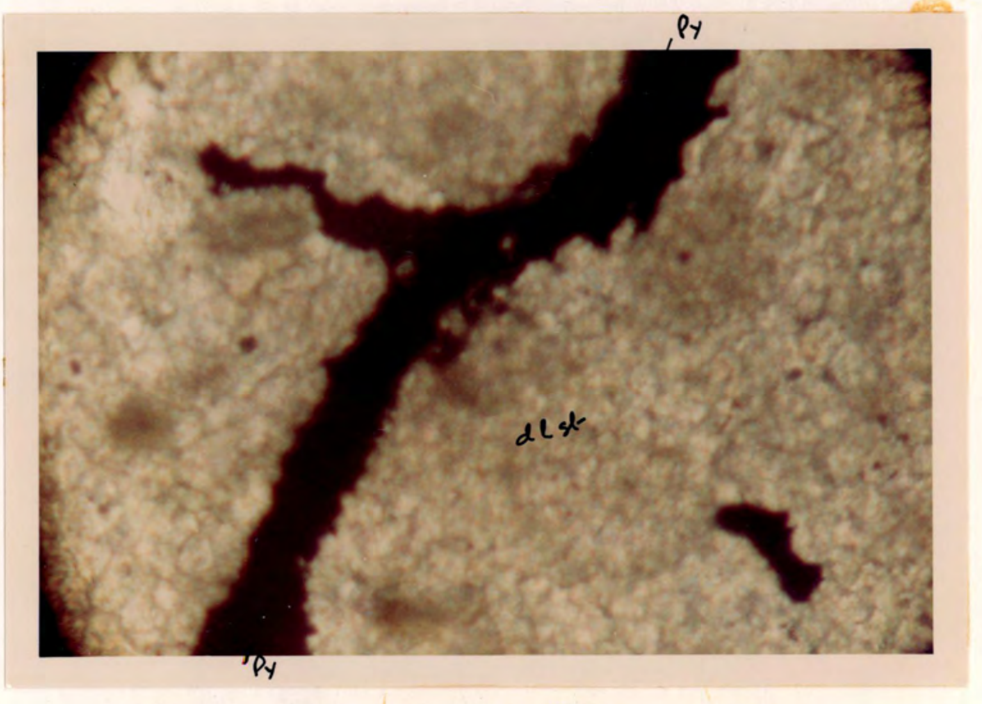

Figure 21.--Photomicrograph showing matching walls and pyrite veins.

Py = pyrite dlst = dolomitized limestone

Figure 22.--Photomicrograph showing veinlets of pyrite cutting across the oolite.

Py = pyrite dlst = dolomitized limestone

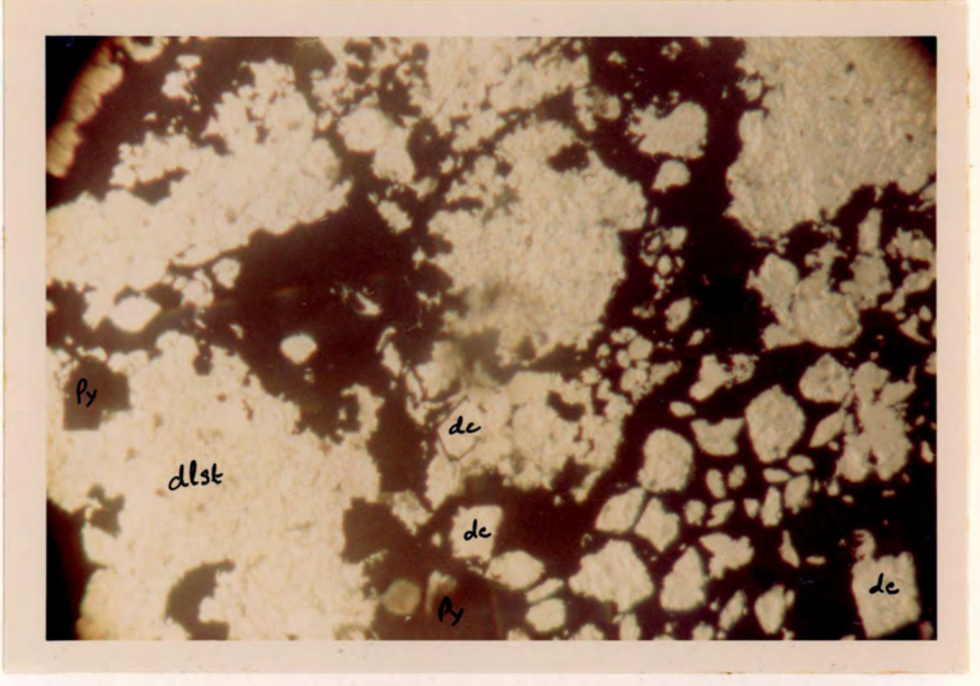

Figure 23.—Photomicrograph showing islands of host rock in pyrite. On the left pyrite can be seen replacing dolomite crystals.

Py = pyrite dlst = dolomitized limestone
dc = dolomite crystal

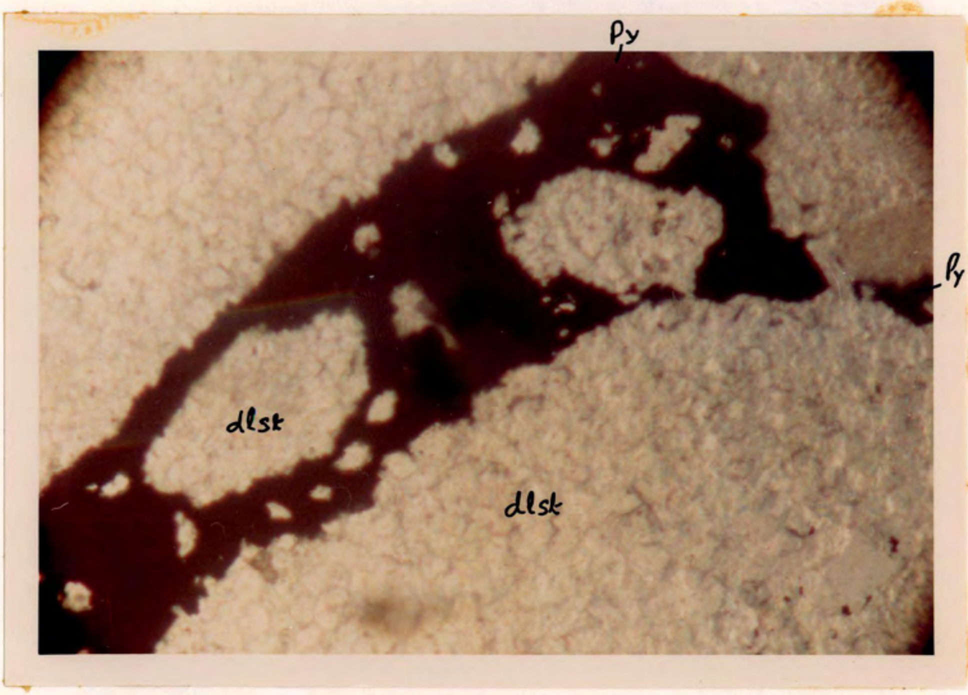

Figure 24.—Photomicrograph showing islands of host rock floating in pyrite.

Py = pyrite dlst = dolomitized limestone

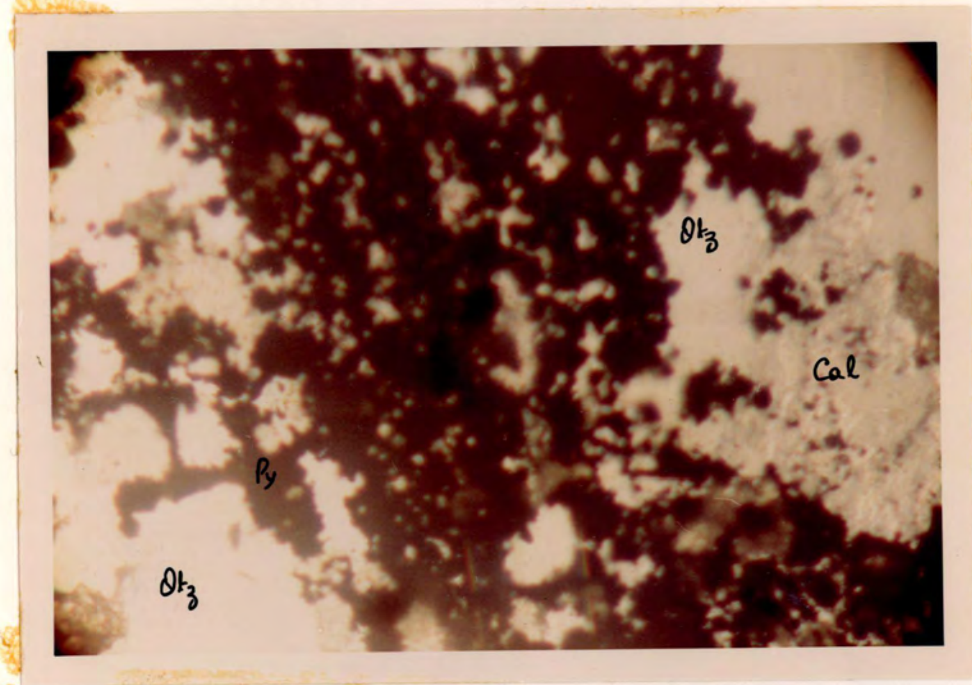

Figure 25.--Photomicrograph showing pyrite
replacing quartz and calcite.

Py = pyrite Cal = calcite
Qtz = quartz

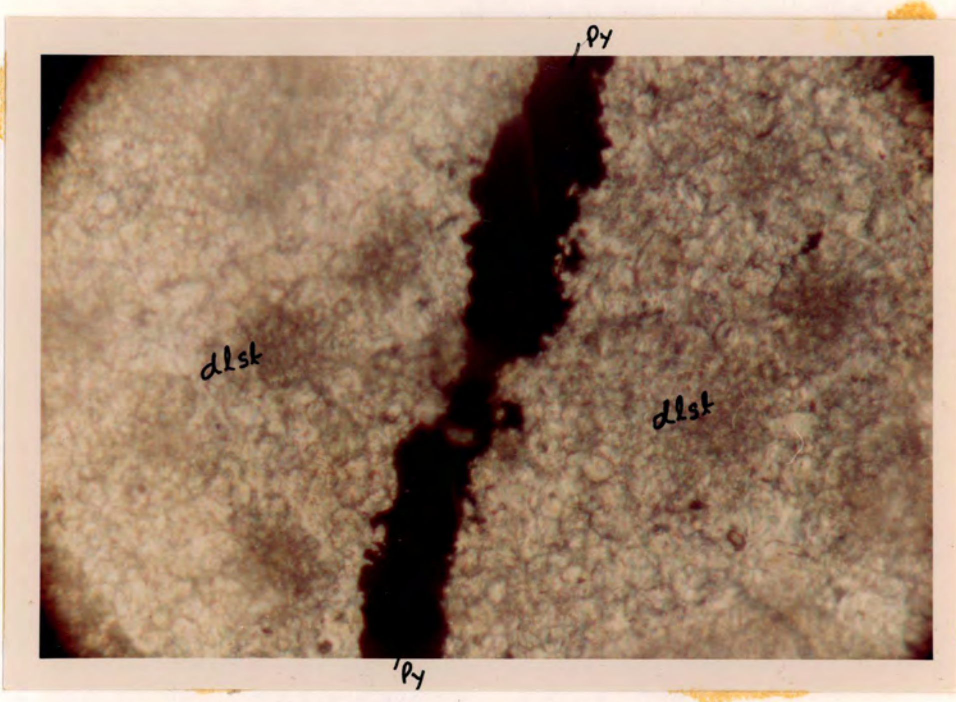

Figure 26. —Photomicrograph showing replacement veinlet of pyrite.

Py = pyrite dlst = dolomitized limestone

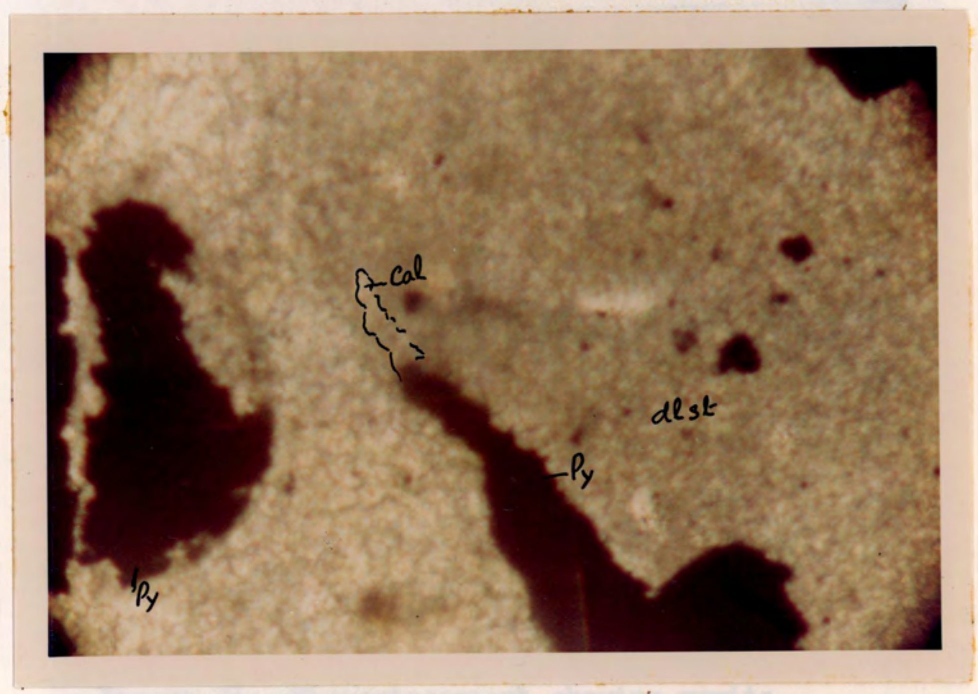

Figure 27. — Photomicrograph showing pyrite vein replacing through calcite vein.
Cal = calcite Py = pyrite

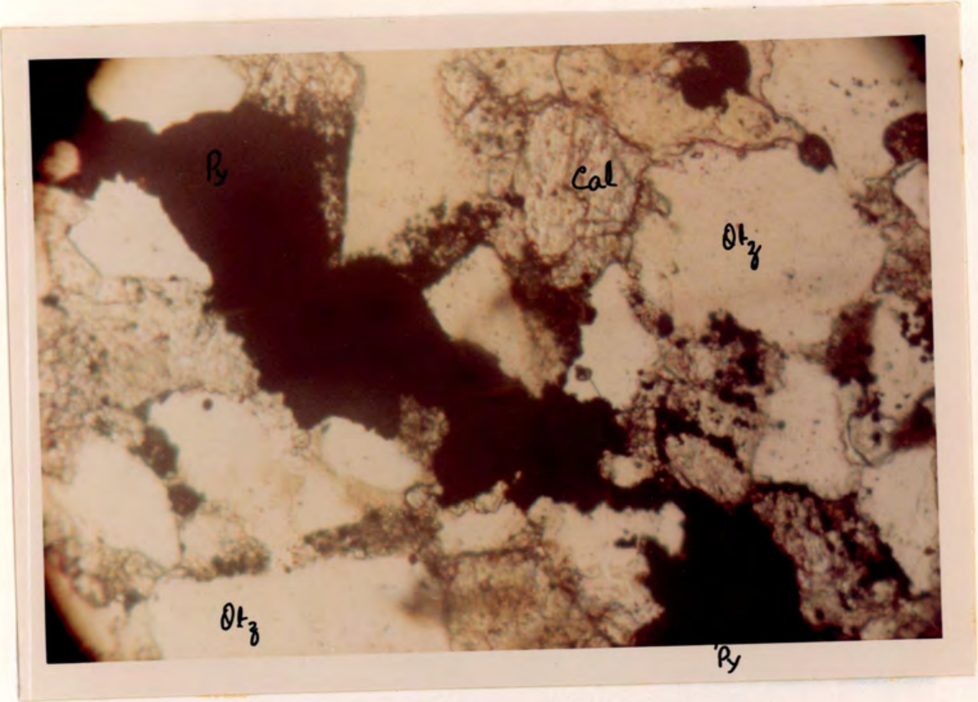

Figure 28.--Photomicrograph showing pyrite replacing calcite.

Py = pyrite, Cal = calcite, Qtz = quartz

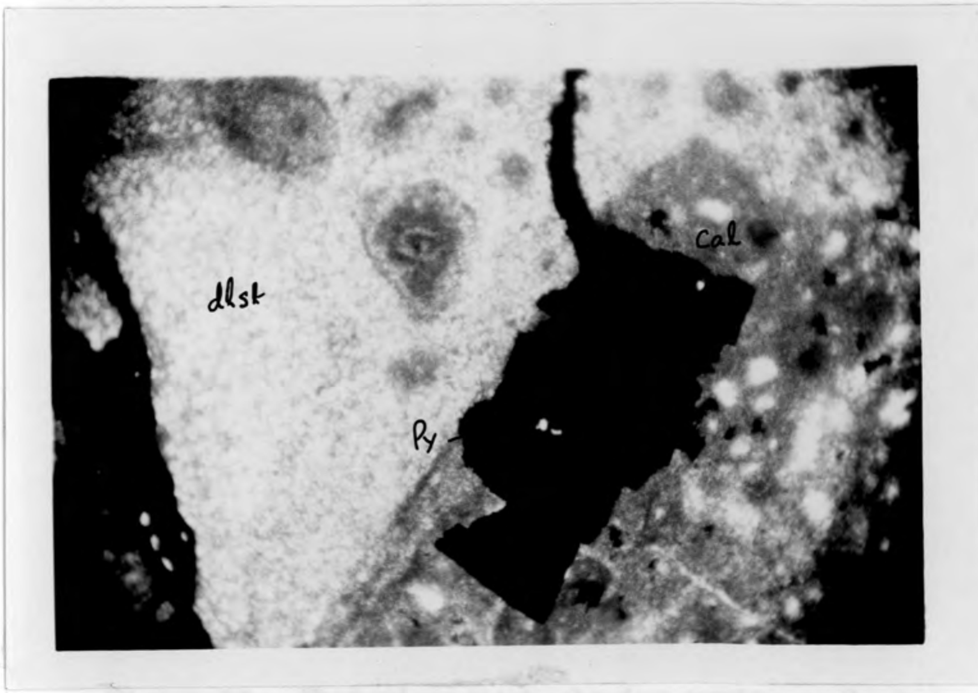

Figure 29.—Photomicrograph showing pyrite selectively replacing calcite.

Py = pyrite dlst = dolomitized limestone
Cal = calcite

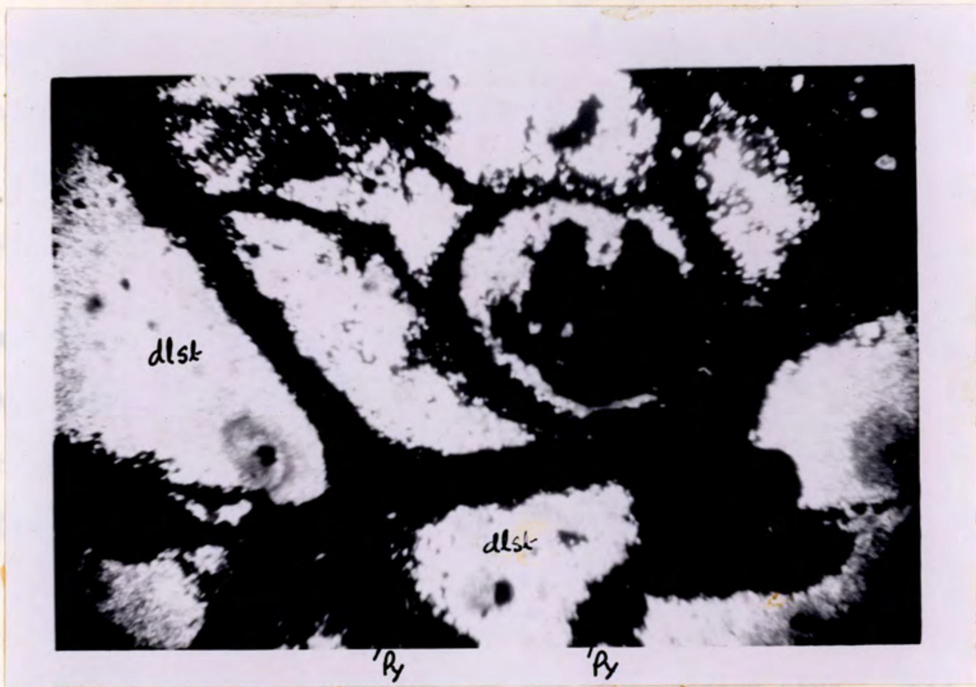

Figure 30. --Photomicrograph showing pyrite replacing along the textural feature of the host rock.
(Matching wall can be seen).

Py = pyrite dlst = dolomitized limestone

In none of the thin sections and polished surfaces were galena and pyrite observed to occur together. Therefore it is possible that pyrite remained in solution for a longer time than galena, and did not precipitate until after the galena precipitated. Similarly there is no definite evidence regarding the time of development of chalcopyrite. Chalcopyrite was not observed to occur with pyrite. Some small specks of chalcopyrite were observed in hand specimens, but its relationship to pyrite and galena could not be determined.

In the writer's opinion the following sequence took place in the deposition of sulfides:

	Early	Late
Chalcedony, quartz, dolomite, and calcite		
Chalcopyrite (?)	?	
Pyrite		
Galena		

ZONING

An apparent zonation is present in the mineralized area. This is shown in the discoloration halo which is at places conspicuous. Apparently the ascending thermal mineralizing fluids coming from depth deposited the least soluble constituents first and the most soluble farthest from the source of mineralizing fluids.

The least soluble mineral (galena) present in the thermal mineralizing fluids precipitated in the lower strata of the North Horn formation. The loss in temperature of the mineraling fluids must have initiated the precipitation of galena.

The soluble contents of the mineralizing fluids travelled farther ascending into fine-grained sandstone, limestone, and conglomeratic sandstone. By this time the fluids cooled and precipitation began. Presumably chalcopyrite precipitated after pyrite.

From the above discussion it is concluded that the zoning and zonal deposition of the sulfides is partially controlled by temperature and partially be the physical chemistry of the mineralizing fluids and the country rock.

It is possible that some of the pyrite and chalcopyrite present in the mineralized area may represnet residual iron and copper in the clastic sediments. Insuch case the hydrothermal solutions reworked or dissolved and later redeposited the syngenetic iron and copper originally present in sedimentary units. Occurrence of pyriteous and carbonaceous shale represents the reduction of original syngenetic iron present in these shale layers. It is possible that reduction of iron and copper took place after the epigenetic fluids were introduced in the formation. Therefore it will be appropriate to classify the syngenetic pyrite of such origin as a "lithogene deposit" as suggested by Lovering (1963, p. 315-331).

ORIGIN OF SULFIDE DEPOSITS

The sulfide deposits present in the area of investigation constitute an interesting problem in regard to their origin. The absence of a strong alteration halo, occurrence of galena and pyrite in clastic sediments, and above all their occurrence in cross-bedded sandstone and conglomerate suggested originally that the mineralization may have been syngenetic. However, detailed examination of mineralized areas and their extent coupled with microscopic study completely eliminated a syngenetic concept of origin for these sulfide deposits.

It will be worthwhile if the record of igneous activity in the Gunnison Plateau is taken into account before pondering on the question of the origin of sulfide deposits in the North Horn formation. In the writer's opinion, the mineralization of the North Horn strata, in the area of investigation, is related to post-Green River igneous activity with the reasons for such given below.

Igneous activity in the Gunnison Plateau

In the immediate area of investigation the only evidence of igneous activity is found in the felsitic lava flows associated with the Green River formation. However, in the western and northern parts of the Gunnison Plateau, monzonite porphyry intrudes the sedimentary units. Hunt (1949, p. 109) described monzonite intrusions located in Little Salt Creek and Four-mile Canyon localities. Quartz monzonite intrusions were described by Zeller (1949, p. 74) from the western part of the Gunnison Plateau. Prior to Zeller's investigations no such intrusive igneous body was reported from the Gunnison Plateau.

Both Hunt (1949, p. 109-116) and Zeller (1949, p. 60-61 and 74), described wall rock alteration from their areas of investigation and reported the occurrence of the following minerals:

Pyrite, calcite, quartz, flourite, apatite, specular hematite and silver and lead minerals.

Several claims were staked along the contact of monzonite with the Arapien (?) limestone. However no deposits of economic importance were discovered.

Quartz monzonite porphyry is present in Mount Nebo area and is seen to cut across gypsum beds associated with the Arapien shale.

The Gunnison Plateau which lies south of Mount Nebo is separated from the latter by Salt Creek Canyon. It is possible that quartz-monzonite porphyry intrusion occur at depth all the way from Mount Nebo south into the Gunnison Plateau, and that the mineralization of the North Horn strata is related to the hydrothermal solutions originating in quartz-monzonite porphyry intrusion. Although, the quartz-monzonite is not exposed in the sedimentary units in the area of investigation, it is postulated that it is present at depth and that late emanations from it ascended into the overlying strata mineralizing the North Horn strata in the area of investigation.

Epigenetic origin versus clastic origin

It was stated previously that galena and pyrite occur in cross-bedded sandstone and conglomerate (pyrite also occurs as a replacement type in limestone). Galena is particularly concentrated in some of the cross bedding laminae. It is also present in coarse grained massive sandstone. Microscopic study of the thin sections of the mineralized sandstone does not show any characteristics for assigning a clastic origin either to galena or pyrite.

a. The following points repudiate a clastic or syngenetic origin for the galena deposits:

i. A study of several thin sections of the galena bearing specimens reveals no rounding and abrasion of galena fragments. Being a soft mineral galena grains should show a degree of roundness if they were clastic particles. This is not the case.

ii. Study of thin sections of the galena bearing specimens reveals that galena does not occur as an original material cementing or a component of the original cement. It occurs in the midst of the cement. "Islands" of the cement can be seen in galena. Figures 9 and 10 show this feature.

iii. Galena replaces calcite and assumes a pseudo rhombic outline.

iv. In hand-specimens galena occurs throughly intermixed with other constituents of sandstone even though galena is many times heavier than any other clastic particle. The intermixing of galena and sand grains defy gravity stratification. Moreover if galena was transported along with the rest of the constituents of the sandstone than it might have formed as a part of traction load. In such case galena should occur in concentrations as distinct layers consisting of well sorted and well rounded grains.

v. Galena and pyrite deposits were observed cutting across different rock facies. Galena occurs both in conglomerate and sandstone, whereas pyrite occurs in conglomerate, sandstone, and limestone.

b. The following points repudiate a clastic or syngenetic origin for the pyrite deposits:

i. Pyrite does not occur as rounded grains. It rather occurs as crystalline. Pyrite is observed assuming pseudo-rhombic outline by replacing calcite and dolomite.

ii. Pyrite is distinctly observed replacing calcite filled veins in limestone.

iii. Pyrite replacement occurs along the pre-existing textural features of the host rock (fig. 16).

iv. The host rock islands occur in pyrite (fig. 20).

v. Replacement of calcite cement by pyrite and the subsequent replacement of pyrite by quartz clearly indicates epigenetic origin of pyrite.

vi. Pyrite occurs in three different rock facies, limestone, sandstone, and conglomerates.

Epigenetic origin versus biochemical origin

A detail lithological study of the North Horn formation will reveal that the entire formation is a clastic sedimentary body with minor amounts of limestone. The primary structures of the formation indicate that the formation was deposited by running water draining into a shallow basin undergoing differential subsidence. It is apparent that the basin remained extremely turbulant throughout the deposition of the North Horn strata. The constant inflow of sediment ladden water kept this basin well aerated (at least the part of the basin which constituted the present area of investigation). Such environments are hardly conducive to the flourishing of anaerobic bacteria and the subsequent precipitation of sulfides. Moreover the absence of carbonaceous shale (most of the biochemical suflide deposits are associated with black shales) and any noticeable carbonaceous material indicates that the supply of organic material was almost lacking locally but abundant in strata near sulfide mineralization. The absence of plant fossils in the North Horn strata of the area of mineralization indicates the almost organically barren nature of the adjacent sediments.

An extensive study of the shale and sandstone strata present in Coal Canyon revealed no associated metallic deposits, even though the environments, at the time when these strata were being deposited, were most favorable for the fourishing of sulfur secreting bacteria.

CONCLUSION

From the foregoing discussion it is apparent that the galena and pyrite deposits in the North Horn strata are epigenetic. Furthermore these deposits are related to the Tertiary igneous activity which occurred in post-Green River times.

Most probably the mineralizing solutions ascended from a cooling igneous intrusive body at considerable depth. While ascending from depths, the mineralizing fluids lost much of their heat, underwent drastic chemical changes, and cooled when these fluids reached the present site of mineralization. As a result of loss of heat and decrease in chemical reactivity, the fluids did not cause intense wall rock alteration. Consequently a pronounced alteration halo is lacking. This is very characteristic of hydrothermal fluids which are telescoped from greater depths. In the writer's opinion the galena and pyrite deposits in the North Horn strata present along the plateau front and Rock Creek belong to the category of the telethermal type of mineralization.

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